VELOCITY, KINETIC ENERGY, AND PRESSURE DEVIATIONS RESULTING FROM THE ADAPTATION OF A SECONDARY PROPELLANT CHAMBER ON A 30-06 RIFLE BARREL

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THESIS

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Velocity, Kinetic Energy, and Pressure Deviations Resulting from the Adaptation of a Secondary Propellant Chamber on a 30-06 Rifle Barrel

by

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Lieutenant, United States Navy
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ABSTRACT

A secondary chamber was adapted to a 30-06 pressure barrel as a means for increasing muzzle velocity without exceeding the barrel pressure rating. Ignition of the secondary charge was accomplished by the high pressure gases behind the bullet. Resulting muzzle velocities were determined for various amounts of three granular and one liquid propellant. Pressure-time curves were obtained for one of the faster burning powders. Adiabatic bomb calorimeter testing and published data were used to determine the heats of combustion. The data suggested that the rate of energy release, and not the heat of combustion, was the dominant factor in this experiment. A velocity increase of three per cent and a kinetic energy increase of seven per cent were obtained for eight milliliters of secondary charge. The results also indicated that a more optimum location of the secondary charge was possible.

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[illegible]

I. INTRODUCTION

The purpose of this study was to investigate the possibility of increasing the muzzle velocity of a projectile without increasing the maximum breech pressure within the weapon's chamber. Since the muzzle velocity of a bullet is primarily dependent upon internal pressure within the barrel as well as barrel length and projectile weight, it would seem impossible to obtain a change in velocity if these three variables remained constant. Indeed this is true for weapons employing a single powder charge and yielding a standard pressure pulse. Such weapons constitute almost all of the firearms produced by today's technology. This study considered the addition of a second powder chamber suitably placed along the barrel in order to increase the muzzle velocity. The theory behind this modification, its initial design, and its experimental use will be discussed.

Since early man cast his first stone at some prehistoric animal, he has been trying to better the accuracy and increase the range of his weapons. This quest can be traced from that prehistoric stone to David and his sling, from the longbow to the much feared crossbow, and in more recent times from the flintlock to the long range German supergun or Hochdruckpumpe as it was known during World War II. [Ref. 1].

This supergun was the only example that could be found that even remotely resembled the principle of additional powder chambers. It was designed to fire an arrow projectile

across the English Channel to London. This weapon had a 15 centimeter bore and consisted of forty interchangeable sections. Twelve of these sections contained double powder chambers aligned at a slight inclination toward the muzzle and stationed at various intervals along the barrel. As the projectile progressed along the sections, it set off the powder charges in the double chambers causing successive explosions from behind which boosted the missile to a muzzle velocity of 4500 feet per second.

This feat was not easy, for enormous internal pressures were required along the entire length of the bore to accelerate the 150 pound, three-foot projectile. In fact, it was reported that a section of the barrel exploded about once every three shots. When the gun was given a 50 degree angle of inclination, it had a range of 130 kilometers, more than enough to reach across the channel to London. Luckily the German Hochdruckpumpe installation was bombed before completion.

The sequence of events behind a normal gun being fired is that once the primer ignites and the propellant begins to burn, pressure slowly builds up inside the breech until it reaches a maximum. Concurrently this pressure exerts a force which accelerates a projectile down the bore. Here the word slowly is used in a relative sense, since the pressure rise is not a spike but rather a steep smooth curve as illustrated in figure 1. This type of rise is due to the fact that the charge must build up its own internal pressure as it ignites.

The higher the pressure, the faster the powder will burn. The idea behind this study was to place a second powder charge about halfway down a gun barrel and to measure the resulting pressure rise and its effect on muzzle velocity. An educated guess was used in locating the position of this secondary charge and no doubt, its location will have to be changed for best results.

Normally this maximum pressure is accompanied by a maximum internal temperature, for at this point the propellant is burning strongly. As the bullet progresses down the barrel, the internal volume will quickly increase causing the pressure to drastically decrease. Also, once the propellant is completely burnt, the temperature will rapidly drop causing a still greater pressure decrease until the bullet exits the barrel. At this point the pressure will level off at ambient.

If a second charge were set off to coincide with the drop off in pressure, a new burst of energy would be introduced into the system causing a second rise in the pressure time trace as illustrated in figure 2. Ideally this second pressure rise should be adjusted to peak out at the original pressure level so that the design limits of the weapon are not exceeded. If desired, multiple secondary chambers could be used to give a fairly constant pressure level along the entire length of the barrel. Essentially this was the idea behind the German supergun.

It is interesting to note that the second pressure buildup is almost a vertical line on the pressure-time curve. This

is because the barrel already has a high internal pressure for the powder to deflagrate within and, as stated before, the higher the pressure the quicker the propellant burns. This second pressure peak will now degenerate as the volume and temperature inside the barrel change, just like the normal charge. However, the bullet will now sense a higher average pressure pushing it from behind. This higher average pressure will result in a greater muzzle velocity.

A higher muzzle velocity has several advantages. First it results in a shorter time of flight, which is extremely important when looked at from the point of leading a moving target. Also, if looked at from a military sense, it is better to hit a target fast or the target may have time for defensive maneuvers. A higher muzzle velocity also increases the kinetic energy of the projectile. This kinetic energy increase will result in a greater shocking power and will increase the kill probability or allow for a lighter bullet to cause the same effect as a slower, heavier one. Range is another consideration; an increase in velocity will result in an increase in range and, in many cases, an increase in accuracy.

II. METHOD OF INVESTIGATION

This experiment used a 30-06 caliber pressure barrel having a pressure transducer installed near the breech. The barrel was modified to hold a screw-in secondary powder chamber midway down the bore. A standard round of 30-06 ammunition was used to establish a base velocity and once found, this velocity was increased by using from one to nine grains of secondary charge of various types of powder and from one to eight milliliters of a liquid propellant. Velocity readings were obtained using a chronograph and pressure readings were recorded on film from an oscilloscope. The data were tabulated and plotted using an IBM-360 computer.

III. EXPERIMENTAL APPARATUS

The test apparatus used in this experiment can be divided into three basic parts; the rifle with its secondary chamber, the pressure sensing transducer installation, and the time measuring chronograph. Figure 3 shows the weapon with its chamber and transducer mountings, figure 4 presents an overview of the indoor test range used, and figure 5 shows the electronic data acquisition setup.

For safety, a U.S. Springfield Armory model #1903 action was coupled to a 20 inch, 30 caliber pressure barrel. Before this match was made, the breech of the barrel had to be reamed to chamber standard 30-06 ammunition. This combination

easily withstood breech pressures approaching 60,000 psi. The rifle was mounted on a test bench with two aluminum mounting clamps as illustrated in figure 4. These aluminum mounts, once tightened, made a vice-like grip with little or no alignment freedom. Therefore, once mounted, both screens and trap were placed in line with the boresight.

Ten inches down the pressure barrel a 2 inch wide, 5/16 inch thick piece of steel was heat shrunk over the original barrel, creating a strengthened section for the mounting of the secondary chamber. Two screw-in chambers of different internal volumes were used in the tests. One had a small inner diameter of 1/4 inch for charges of from zero to four grains of secondary powder, and the other, having a larger diameter of 1/2 inch, was loaded with five to nine grains. Figure 6 is a photograph of the chamber mount showing both screw-in chambers and figure 8 presents the details. A 11/64 inch diameter relief hole was drilled through the bottom half of the rifle into the center of the secondary chamber. This relief hole served two major functions. First it allowed the hot, high pressured exhaust gases immediately behind the bullet to enter the chamber. The hot gases ignite the secondary charge and the high pressure makes it burn quickly. This causes a pressure rise in the secondary chamber. The relief hole then acts as a pressure source by allowing the higher pressure in the chamber to exit into the barrel until both pressures equalize. This results in a slightly higher internal pressure behind the projectile.

The pressure sensing was accomplished utilizing a Kistler quartz pressure transducer, model 607-A. A mounting location just ahead of where the cartridge case ends was chosen since this location gave the most accurate breech pressure readings. Once again, the barrel was strengthened similar to the method used for the secondary chamber. An initial attempt to mount the transducer without this strengthened section resulted in the Kistler ripping out of its mounting threads. Figure 7 shows the transducer with its mount and figure 8 is a detailed drawing closely following the Kistler Instrument Company's preferred installation recommendations.

A low noise microdot transducer cable connected the pressure transducer to a Kistler 504-A charge amplifier. The amplifier stepped up the weak pressure-generated signal to a level sufficient enough to be displayed on an oscilloscope. This signal was sent to the trigger input of the scope as a negative external D.C. source. When a pulse was generated, it triggered the horizontal sweep which was set to move across the scope face at a rate of one centimeter every 100 microseconds. The vertical scale on the scope was set at 0.5 volts per centimeter and the charge amplifier output on a range of 20,000 psi per volt. This worked out to a vertical display scale of 10,000 psi per centimeter on the oscilloscope grid. The resulting pressure time curves were photographed with a Polaroid camera.

Muzzle velocities were ascertained using a chronograph which measured the projectile's time of flight, in microseconds,

between two down-range gates. A ten foot interval was used between gates and a fourteen foot distance was maintained between the muzzle of the barrel and the starting gate. This fourteen foot distance was necessary to insure that the fragile chronograph screens would not be torn by the muzzle blast. Autron Counter Chronograph Screens were used since these screens were low cost, very dependable, and worked on a break contact principle. A new screen was required at both gates prior to each shot. Figure 9 is a wiring diagram showing the linkup between the chronograph and pressure sensing components of the test apparatus. One of the key components in this setup was the NPN Switching Transistor which, once installed, solved a problem of a stray electrical pulse that was plaguing the data acquisition effort. When this transistor switch was coupled to the Autron screens a chronograph dependability of 100% was realized. Prior to this, the system had a reliability of approximately 33%.

The actual time of flight of the projectile was measured and displayed by a AN/USM-245A electronic digital readout counter. This counter was fed inputs from the start and stop gates and it displayed the time, in microseconds, it took for the projectile to travel the ten foot distance between screens. Once the projectile transited the time gates, it entered an armor steel bullet trap.

IV. EXPERIMENTAL PROCEDURES

The first step in the data taking process was to insure that the rifle and its secondary chamber would safely handle the expected breech pressures. Once the rifle was mounted on its test bench, the bullet trap was aligned with the bore-sight and four 25 pound lead blocks were used to hold it in place. Standard Winchester 180 grain soft point bullets were used for the initial firing. The small volume secondary chamber was installed empty and the first shot proceeded without incident. Four grains of Du Pont pistol powder were placed in the small chamber and again the weapon was fired. When the chamber was removed for inspection, it was noted that the charge had indeed ignited leaving no trace of residue.

This second shot proved that the gases behind the bullet were hot enough to ignite the charge within the chamber. Up to this point it was debatable whether or not the gases would set off the powder or if an alternate firing mechanism would be needed. To check the integrity of the rifle under maximum pressures, the larger secondary chamber was loaded to capacity with eight grains of Du Pont pistol powder. Again the weapon was fired and again the secondary charge was set off with no structural damage to any component. With the completion of this shot, the rifle and its chamber were considered safe for use.

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The chronograph was the next piece of equipment to be checked out, for it was needed to determine whether or not the added charge actually increased the bullet velocity. At first a circut was designed using chronograph screens which made contact as the bullet ripped through them. However, this circut had to be scrapped since the bullet created multiple electrical pulses while passing through the start gate, causing the timer to stop almost as soon as it started. A new circut, using NPN switching transistors and Autron break contact chronograph screens, was then designed. This apparatus proved to be an adequate chronograph. Once the bugs were worked out of the system, a rough base velocity, using no secondary charge, was established. Then the chamber was filled with a maximum load of pistol powder and the weapon fired. The resulting velocity was about 100 feet per second above the base velocity. This shot indicated the feasibility of the technique. A velocity increase of 100 ft/s in 2700 ft/s represents about a 4% velocity increase for eight grains of secondary powder.

The relief hole was considered next. It was thought that a greater velocity increase would be realized if the diameter of the relief hole were maximized. Using the initially designed relief hole diameter of 9/64 of an inch, three velocities were measured using eight grains of secondary powder. This provided a velocity base. The hole was enlarged to a 5/32 inch and then to a 11/64 inch diameter. For each hole diameter a new velocity was measured. When this series of

tests were completed and the results reviewed, it was found that all velocities were within ten feet per second. This meant that the relief hole was already large enough to relieve the chamber pressure and any further enlargement had no measurable effect.

The system was now ready for the acquisition of velocity data. Winchester 180 grain soft point bullets were selected for the remaining velocity testing since this was a popular ammunition and it gave repeatable results during the initial checkout phase. When the ammunition was chosen and the distance between screens set at exactly ten feet, six shots were fired to establish an accurate base velocity. These shots were taken with no secondary charge and they averaged to 2772 ft/s ($\pm$ 6.5 ft/s). Du Pont pistol powder #5066 was used for the initial secondary charge. The series used from one to eight grains of secondary powder in increments of one grain. Each increment was carefully measured on a grain balance scale and placed in the appropriate secondary chamber. Two shots were taken for each secondary load and the resulting time intervals were recorded off the face of the digital counter. The data were converted to velocities and plotted against grains of secondary powder to check the smoothness of the curve.

The testing was repeated using several different propellants. Hercules Bullseye Pistol Powder was selected along with Du Pont Pistol Powder since these two were among the fastest burning powders on the market. For a further comparison, a slower burning military rifle powder, Du Pont IMR-4320,

was used. A comparison of this powder with the faster pistol powder would show the effect of secondary charge burn rate on the system. In addition to the granular powders, one of the latest liquid propellants was tested. The liquid selected was one which the Navy is now in the process of testing in its liquid propelled gun project. The composition of this liquid propellant and its performance data are classified, therefore, it will be referred to as Liquid A in this study. The same ignition system, which was used on the granular powders, was sufficient to ignite Liquid A. The only problem encountered with this propellant was that it was highly corrosive, requiring the barrel and chambers to be cleansed after each test.

A computer program was written to take the velocity readings and perform a least squares fit on the data. Fits of from first to seventh degree were tried with the resulting higher degrees too erratic for use. A third degree least squares fit was finally chosen, because of its smoothness, for use on all computer plots. With the desired fit determined, the computer program was modified to operate on the least squares coefficients giving 200 interpolated values of velocity change vs. grains of powder. The measured velocity readings were next converted to kinetic energies. The computer program was again modified to take this information and plot out changes in kinetic energy vs. grains of secondary powder, along with a table of 200 interpolated values. When all the computations were made, the computer was instructed

to tabulate this information on a data sheet. The resulting data sheets, tables, and plots are included in the data section.

As an aid in determing just how much energy was released into the system by the secondary charge, the heat of combustion of the four propellants was needed. An adiabatic oxygen bomb calorimeter was used to gather this information. The first step in finding the heats of combustion was to calibrate the bomb by finding the amount of calories it took to raise its temperature one degree centigrade. This value was called the correction constant "K". To obtain "K", a measured amount of benzoric acid, which yielded a known number of calories per gram when ignited, was burned to completion within the bomb. By recording the initial and final temperatures, the correction constant was obtained. Two such tests were conducted and their results are presented in Appendix A.

With "K" known, heat of combustion tests were run on the three granular propellants and the results are included in Appendix A. Again two tests were made on each propellant and one may note that the results of each pair of calculations were very close. However, when the liquid propellant was tried, it would not burn to completion. Instead the constituents of Liquid A had to be analyzed separately. The heats of combustion were found either from published data or from calorimeter testing. When these values were multiplied by their composition percentages and added together, they gave a heat of combustion of 1248 calories per gram. This was

close to a rough predicted value which had been obtained from the prior bomb tests which failed to go to completion.

The final test was the most important series in this study. It attempted to take pressure and velocity readings for one selected propellant, using matched ammunition. If a pressure-time trace such as the one depicted in figure 2 could be acquired, it would show whether or not the amount of secondary charge was sufficient to drive the pressure back up to the maximum pressure or, perhaps more important, whether the location of the secondary chamber need be changed to align the peak of the secondary pressure spike with the maximum pressure. Matched ammunition was used in this test to insure a repeatable base velocity throughout the series. The matched ammunition used was Winchester preprimed 30-06 Springfield cartridge cases. Each cartridge was loaded with 50.5 grains of Du Pont IMR-4320 military rifle powder and joined to a Sierra 180 grain, .30 caliber Spitzer flat base rifle bullet. The Sierra Loading Manual [Ref. 2], lists a muzzle velocity of 2732 ft/s and a maximum breech pressure of 50,800 psi for this combination.

The pressure barrel was modified, as shown in figure 8, to hold the pressure transducer. When the modification was completed, the remaining pressure sensing equipment was connected as shown in figure 9. A base velocity of 2725 ft/s was determined for the matched ammunition. Hercules Bullseye pistol powder was chosen as the secondary propellant for this last test series. Once again two shots were taken for each

one grain increment of secondary powder and the resulting time interval and pressure-time trace were recorded for each shot. A warning should be included at this point. The Kistler pressure transducer is a very fragile piece of equipment and care must be taken to insure that it operates within its design temperature and pressure limitations. During this test the transudcer was removed from its mount and cleansed of foreign deposits after every second shot. Failure to do so resulted in a clogged inlet port, causing erroneous pressure readings.

Figure 10 depicts the pressure-time traces obtained from this series. For clarity, a time scale which neglects to show the bullet exiting the barrel was chosen. However, this part of the trace was of little interest as demonstrated in a comparison of figures 10(e) and (k). Figure 10(k) is for the same secondary charge as figure 10(e) but it shows a longer time trace. At the conclusion of the series the data were fed into the IBM-360 computer. The resulting plots and tables are included in the data section.

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V. RESULTS AND DISCUSSION

The velocity-charge weight and kinetic energy-charge weight curves obtained from the initial series of tests formed a smooth progression of data points in all but one instance. The test using Du Pont military rifle powder as a secondary charge was the exception. Picking the velocity increase vs. grains Du Pont pistol powder curve as a representative plot, one might notice that the curve has several distinct features. For instance, the curve displays a fast rise in velocity at from one to three grains of secondary powder followed by a level section between four and five grains, and then a renewed rising velocity from six grains to the end of the plot. This leveling of the curve at its center might be partly explained as a point of inflection for the third degree least squares fit or perhaps it might be explained as an idiosyncrasy of the experimental apparatus. As already stated, two secondary chambers, each having a different internal volume, were used. The smaller cylinder was used for charges of from one to four grains of powder and the larger chamber was installed with charges of from five to eight or nine grains of secondary. When the smaller chamber was loaded with only one grain, it was filled to 1/4 of its internal volume. This left an excess volume of three cubic millimeters. When the charge was ignited, this excess volume could have caused a small pressure drop.

[illegible]

This void was reduced as the amount of charge increased until four grains of secondary powder were used. When loaded with this measure, the chamber was filled to capacity and no dead space remained. At this point the chamber experienced the maximum pressure buildup for its fixed volume. However, when five grains of secondary powder were used in the larger chamber (having twice the internal volume of the smaller), this resulted in a chamber having an eight grain capacity being loaded with only five grains of powder. This left a three grain void which may have caused a slight pressure drop. The resulting pressure could cause a lower muzzle velocity, producing the level section on the curve between four and five grains of powder.

Unfortuantely this phenomenon was not noticed until after all tests were completed and the data reviewed. It was felt that more accurate readings might have been obtained if this excess volume was eliminated. Two suggested methods for its elimination are to use eight different chambers, each having an internal volume matched to that of the desired load, or to use machined metal plugs as fillers in the existing chambers. Either method would eliminate the void and possibly do away with the level section noticeable on many of the plots.

The (+) symbols on the computer plots represent the actual measured data points. Each increment of powder has two such points above it and the average of these two points was the raw data fed into the least squares fit routine. The accuracy of these points are dependent on two main items:

the deviation of the base velocity about the average base velocity computed and the accuracy of the electronic equipment. The base velocity determined for the Winchester ammunition was measured at 2772 $\pm$ 6.5 ft/s making it the primary source of error. The electronic equipment can be divided into two error generating sections, the start-stop gates and the digital counter. However, the start-stop gate error can be discounted since any time delay between the breaking of the first chronograph screen and the starting of the timer would be cancelled by the breaking of the other screen stopping the timer. In other words, both gates have the same inherent delay error, resulting in an unaffected interval of time. The chronograph timer does have a roundoff error of $\pm$ 1 microsecond which converts to a $\pm$ 0.8 ft/s at average velocities. These factors result in a maximum error of 7.3 ft/s in the reported velocities. Applying the same error analysis to the kinetic energy yields a maximum error of 16.2 ft-lbs.

Three of the propellants gave almost identical results. These were the two pistol powders and Liquid A. Hercules Bullseye pistol powder yielded a mean velocity increase of 91.3 ft/s and a kinetic energy increase of 205.9 ft-lbs for eight grains of secondary charge. This resulted in a 3.29% velocity increase and a 6.70% kinetic energy increase. The performance of Du Pont pistol powder was approximately the same in that it gave a velocity increase of 3.07% and a kinetic energy increase of 6.37% for the same maximum secondary

powder charge. However, the liquid propellant seemed to slightly outperform both pistol powders. It gave a 3.31% velocity increase and a 6.73% kinetic energy increase for eight milliliters of Liquid A. Note that Liquid A plots use milliliters liquid vice grains of powder. This measure was chosen since it was considered easier to meter a volume of liquid. For comparison, one milliliter of liquid roughly filled the same volume as one grain of granular powder.

The slower burning Du Pont military powder IMR-4320 gave erratic results. The results were so erratic that only the velocity and kinetic energy data points were plotted and no attempt was made to perform a least squares fit. The resulting curves and tables of interpolated points would be meaningless. However, this data did show some interesting results. It was noted that the velocities obtained from only one grain of secondary powder showed a poor velocity increase, and at times a definite velocity decrease. This was not the result of erroneous velocity readings, for the base velocity of the ammunition was rechecked. Also these findings were determined from repeated tests. A possible explanation for this velocity drop is presented. A certain amount of energy is absorbed into the secondary charge in order to heat the powder to its flash point. Once the powder was ignited, its burning rate was not fast enough to put this energy back into the system before the bullet exited the muzzle. This might account for the fact that the faster burning pistol powders failed to show a similar trend. Still another discrepancy

was noted with the rifle powder. Measured velocities varied from shot to shot. A possible explanation for this might be that the exposed surface of the powder ignited unevenly causing the flame to propagate non-uniformly. This would cause different burning rates between similar shots, resulting in erratic velocities.

Du Pont pistol powder had a heat of combustion 11.11% greater than that for Hercules. However, the velocity increase obtained from both propellants were virtually the same. This indicated that Hercules pistol powder, even though it had less total energy, probably had a faster burn rate and therefore gave better results in this type of apparatus. This fact can be more dramatically demonstrated when comparing Du Pont pistol powder with Liquid A, whose heat of combustion was found to be 1248 calories per gram. For equal volumes of propellant, Liquid A had approximately ten times the available energy. However, the velocity increases obtained were essentially the same. This might indicate that the liquid propellant had a burn rate somewhat slower than Du Pont pistol powder, but yet fast enough to release its energy prior to the bullet exiting the barrel. Thus, a comparison of the heats of combustion of the different propellants shows that the rate of energy release may have more effect on the muzzle velocity than the amount of "stored energy" available.

The final test, using matched ammunition and Hercules Bullseye pistol powder yielded results very much like the original test series, a 3.72% velocity increase and a 7.57%

kinetic energy increase for eight grains of secondary powder was realized. The important items to analyze here are the resulting pressure-time traces. Striking information was revealed by these traces in that the timing of the secondary charge was not optimized. In fact, the secondary pressure spike arrived about 0.6 milliseconds too late, as can be determined by the trace displayed on figure 10(j). This timing error is the result of a misjudgment in the original design location of the secondary chamber. A suggested improved location for this chamber would be four inches down from the open end of the cartridge case. With the chamber mounted in this position, the secondary pulse should peak at between 0.2 and 0.3 milliseconds, as desired in the original design. As such, the enhanced pressure pulse would push on the projectile for a much longer time period, resulting in a more efficient system and a greater velocity increase.

An analysis of the secondary pressure spike leads to a rough rule of thumb for determining the pressure rise resulting from the secondary charge. Each grain of secondary powder resulted in approximately a 1,000 psi increase in the secondary spike intensity. This increase can be seen on the photo series displayed in figure 10. Another interesting phenomenon was the twin secondary pulse that forms as the amount of charge increases. This double spike most likely resulted from a reflected wave, but the path of the reflection is in doubt. It might originate as a reflection off the breech of the rifle as illustrated in figure 11(a) or it might be a reflection off the bullet as shown in figure 11(b). To help determine

which path the reflected wave took, a rough calculation of the sonic velocity of the gases behind the bullet was made. On the basis of this calculation it was determined that an interval of from three to four inches was present between the initial secondary pulse and the reflected wave. The distance the reflected wave would have to travel in figure 11(a) was measured at six inches, about twice the calculated distance. Also the change in diameter of the cartridge case at the breech forms a damping chamber that would greatly reduce the intensity of the secondary pulse. However, the reflected pulse has about 90% of the intensity of the initial pulse. For these reasons the path shown in figure 11(a) was not considered the most likely path traveled by the reflected wave. Figure 11(b) displays what is believed to be the correct path.

VI. CONCLUSIONS

Hot, high pressure gases behind the bullet were sufficient to ignite both the granular and liquid propellants in the secondary chamber. The resulting pressure rise within the chamber exited through the relief hole to boost the projectile velocity a significant amount, and at no time did the secondary pressure pulse exceed the maximum pressure. The best results were obtained using eight milliliters of Liquid A. This series yielded a 3.31% velocity and a 6.73% kinetic energy increase.

A secondary pressure spike was evident on the pressure-time traces as expected but through a misjudgment in the design location of the secondary chamber, the timing of this pulse was not optimum. For this reason maximum velocity increases were not obtained. After reviewing the data it was determined that the rate at which the propellant burned, and not the heat of combustion, was the dominant factor for increasing muzzle velocity in this system. Therefore, the slower burning rifle powders were not suitable for use in this apparatus, but the faster burning pistol powders gave good performance. The denser liquid propellant, having a slower burn rate, gave comparative velocity increases but, in doing so, required ten times the amount of stored energy.

There is need for additional work in this field. For instance, it is necessary to optimize the position of the secondary chamber. A plot need be constructed comparing chamber location, measured from the breech, versus the obtainable increase in muzzle velocity, for a standard secondary charge. With this type of data it would be possible to determine if the secondary pressure pulse peaks at a specific location or if it continues to rise as the chamber approaches the breech. If the system reacts as the latter, it would approach a limiting case in which the same results might be accomplished by placing a layered mixture of two powders, having different burn rates, within the cartridge case. In this type of setup the slower burning powder would burn first, starting the projectile on its journey down the barrel. With the

bullet in motion, the faster powder would ignite, producing a pulse much the same as the one produced in the secondary chamber used in this study. The apparatus needed for this type of testing would undoubtedly require a pressure barrel having several chambers mounted at given intervals along its length. With this setup constructed the next logical step in the expansion of the experiment would be to try multiple secondary charges. This type of testing would, in theory, approach the German supergun discussed in the introduction.

Two possible applications of this principle are foreseen, one using granular powder and the other a liquid propellant. However, both techniques would be applicable to the same weapon. Because of weight limitations, the type weapons suggested for this modification would have to be either the larger field pieces or the heavier shipboard guns. In either case, the extra weight required for the installation of a secondary chamber would not be a significant factor. Modifications using the granular propellants might require a second breech for quick loading, where the loading, locking and discharge mechanism would be similar to existing breech designs. This second chamber need only be charged when a longer range is required.

The liquid propellant application seems much easier to design and use, for in this case a second breech is not required. Only a simple chamber need be drilled somewhere in the bottom of the gun barrel. When the need arises, this chamber could be filled, through a system of tubes, pumps

and check-valves, with a metered amount of liquid propellant. In this manner, various ranges could be obtained while using a standard shell at a constant angle of inclination. Another advantage of the liquid is that many of today's liquid propellants are safer to store than the granular powders. In fact some will not deflagrate even after being hit by a high speed projectile.

APPENDIX A

COMPUTATION OF ADIABATIC OXYGEN BOMB CALORIMETER CORRECTION CONSTANT

CALORIMETER TYPE:	PARR INSTRUMENT COMPANY SERIES 1200
CALORIMETER NUMBER:	898
BOMB NUMBER:	101A2333
SAMPLE USED:	BENZORIC ACID
CALORIES PER GRAM BENZORIC ACID:	6318

	TEST #I	TEST #II
NET WT. SAMPLE (GRAMS)	1.0195	1.2120
NET WT. WATER (GRAMS)	2002	2011
INITIAL TEMP. (DEG. F)	74.07	74.37
FINAL TEMP. (DEG. F)	78.79	79.95
TEMP. RISE (DEG. F)	4.72	5.58
SPECIFIC HEAT WATER	.998380	.998312
FUSE WIRE CORRECTION (CAL.)	7.0(2.3)	8.0(2.3)
COMPUTED CORRECTION CONSTANT "K" (CAL.) FROM EQUATION BELOW	465.57	468.46

$$\text{SAMPLE (CAL./GM.)} = \frac{(\text{GMS. WATER X SPEC. HEAT WATER} + \text{K})\ \text{DELTA}\ T^{o} - \text{CORR.}}{\text{SAMPLE WT.}}$$

AVERAGE CORRECTION CONSTANT "K" 467.02

HEAT OF COMBUSTION COMPUTATION FOR

DU PONT PISTOL POWDER NO. 5066

CALORIMETER TYPE:	PARR INSTRUMENT COMPANY SERIES 1200
CALORIMETER NUMBER:	898
BOMB NUMBER:	101A2333
SAMPLE USED:	NO. 5066
BOMB CONSTANT "K"	467.02

	TEST #I	TEST #II
NET WT. SAMPLE (GRAMS)	1.0914	1.0228
NET WT. WATER (GRAMS)	2001	2000
INITIAL TEMP. (DEG. F)	78.86	80.34
FINAL TEMP. (DEG. F)	80.72	82.08
TEMP. RISE (DEG. F)	1.86	1.74
SPECIFIC HEAT WATER	.99817	.99812
FUSE WIRE CORRECTION	9.0(2.3)	9.0(2.3)

$$\text{HEAT OF COMBUSTION} = \frac{(\text{GMS. WATER X SPEC. HT WATER} + \text{K})\ \text{DELTA}\ T^{o}C - \text{CORR.}}{\text{SAMPLE WT.}}$$

$$\text{HEAT OF COMBUSTION (CAL./GM.)} = \frac{(2001x.99817+467.02)\ 1.86/1.8 - 2.3(9.0)}{1.0914} = \underline{2314.28}$$

$$\text{HEAT OF COMBUSTION (CAL./GM.)} = \frac{(2000x.99812+467.02)\ 1.74/1.8 - 2.3(9.0)}{1.0228} = \underline{2307.83}$$

AVERAGE HEAT OF COMBUSTION FOR DU PONT NO. 5066 = <u>2311</u> CAL/GM.

HEAT OF COMBUSTION FOR HERCULES

BULLSEYE PISTOL POWDER

CALORIMETER TYPE:	PARR INSTRUMENT COMPANY SERIES 1200
CALORIMETER NUMBER:	898
BOMB NUMBER:	101A2333
SAMPLE USED:	BULLSEYE
BOMB CONSTANT "K"	467.02

	TEST #I	TEST #II
NET WT. SAMPLE (GRAMS)	1.2578	1.2033
NET WT. WATER (GRAMS)	2003	2000
INITIAL TEMP. (DEG. F)	81.46	80.14
FINAL TEMP. (DEG. F)	83.39	81.99
TEMP. RISE (DEG. F)	1.93	1.85
SPECIFIC HEAT WATER	.99809	.99813
FUSE WIRE CORRECTION	9.0(2.3)	9.0(2.3)

$$\text{HEAT OF COMBUSTION} = \frac{(\text{GMS. WATER X SPEC. HT WATER} + \text{K})\ \text{DELTA } T^{\circ}C - \text{CORR.}}{\text{SAMPLE WT.}}$$

$$\text{HEAT OF COMBUSTION (CAL./GM.)} = \frac{(2003\text{x}.99809+467.02)\ 1.93/1.8 - 2.3(9.0)}{1.2578} = \underline{2085.87}$$

$$\text{HEAT OF COMBUSTION (CAL./GM.)} = \frac{(2000\text{x}.99813+467.02)\ 1.85/1.8 - 2.3(9.0)}{1.2033} = \underline{2086.77}$$

AVERAGE HEAT OF COMBUSTION FOR BULLSEYE PISTOL POWDER = 2086 CAL./GM.

[illegible]

[illegible]

[illegible]

[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

HEAT OF COMBUSTION COMPUTATION

FOR DU PONT IMR-4320

CALORIMETER TYPE:	PARR INSTRUMENT COMPANY SERIES 1200
CALORIMETER NUMBER:	898
BOMB NUMBER:	101A2333
SAMPLE USED:	IMR-4320
BOMB CONSTANT "K"	467.02

	TEST #I	TEST #II
NET WT. SAMPLE (GRAMS)	1.0362	1.1424
NET WT. WATER (GRAMS)	1996	1999
INITIAL TEMP. (DEG. F)	74.58	75.68
FINAL TEMP. (DEG. F)	76.51	77.80
TEMP. RISE (DEG. F)	1.93	2.12
SPECIFIC HEAT WATER	.99836	.99829
FUSE WIRE CORRECTION	9.0(2.3)	9.0(2.3)

$$\text{HEAT OF COMBUSTION} = \frac{(\text{GMS. WATER X SPEC. HT WATER + K) DELTA T}^{\circ}\text{C - CORR.}}{\text{SAMPLE WT.}}$$

$$\text{HEAT OF COMBUSTION (CAL./GM.)} = \frac{(1996\text{x}.99836+467.02)\ 1.93/1.8 - 2.3(9.0)}{1.0362} = \underline{2525.28}$$

$$\text{HEAT OF COMBUSTION (CAL./GM.)} = \frac{(1999\text{x}.99829+467.02)\ 2.12/1.8 - 2.3(9.0)}{1.1424} = \underline{2520.74}$$

AVERAGE HEAT OF COMBUSTION FOR DU PONT IMR-4320 = 2523 CAL./GM.

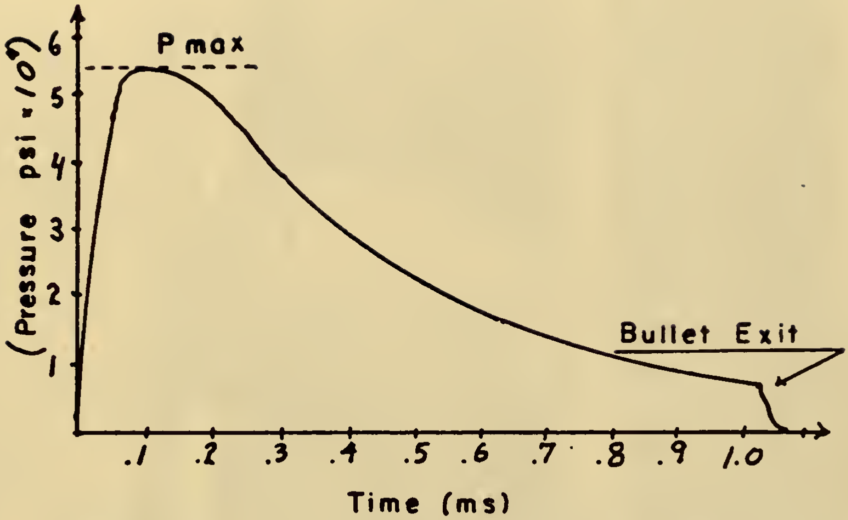


Figure 1. Standard Pressure-Time Trace

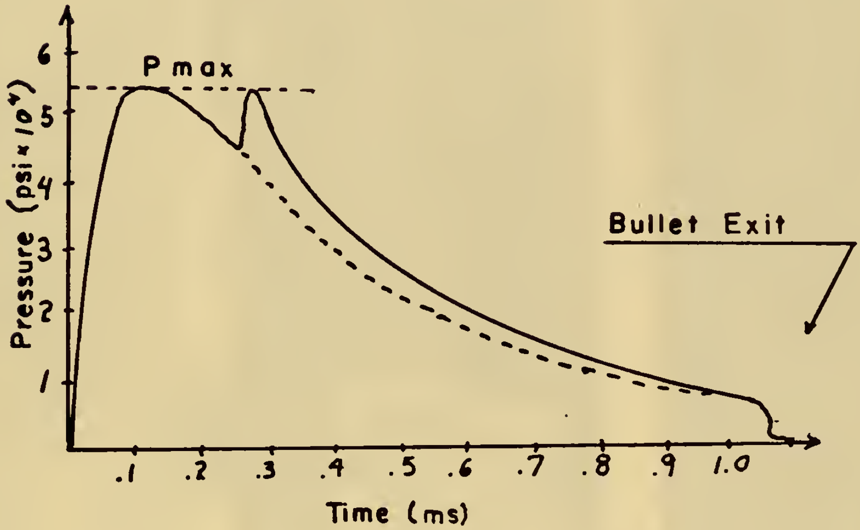


Figure 2. Boosted Pressure-Time Trace

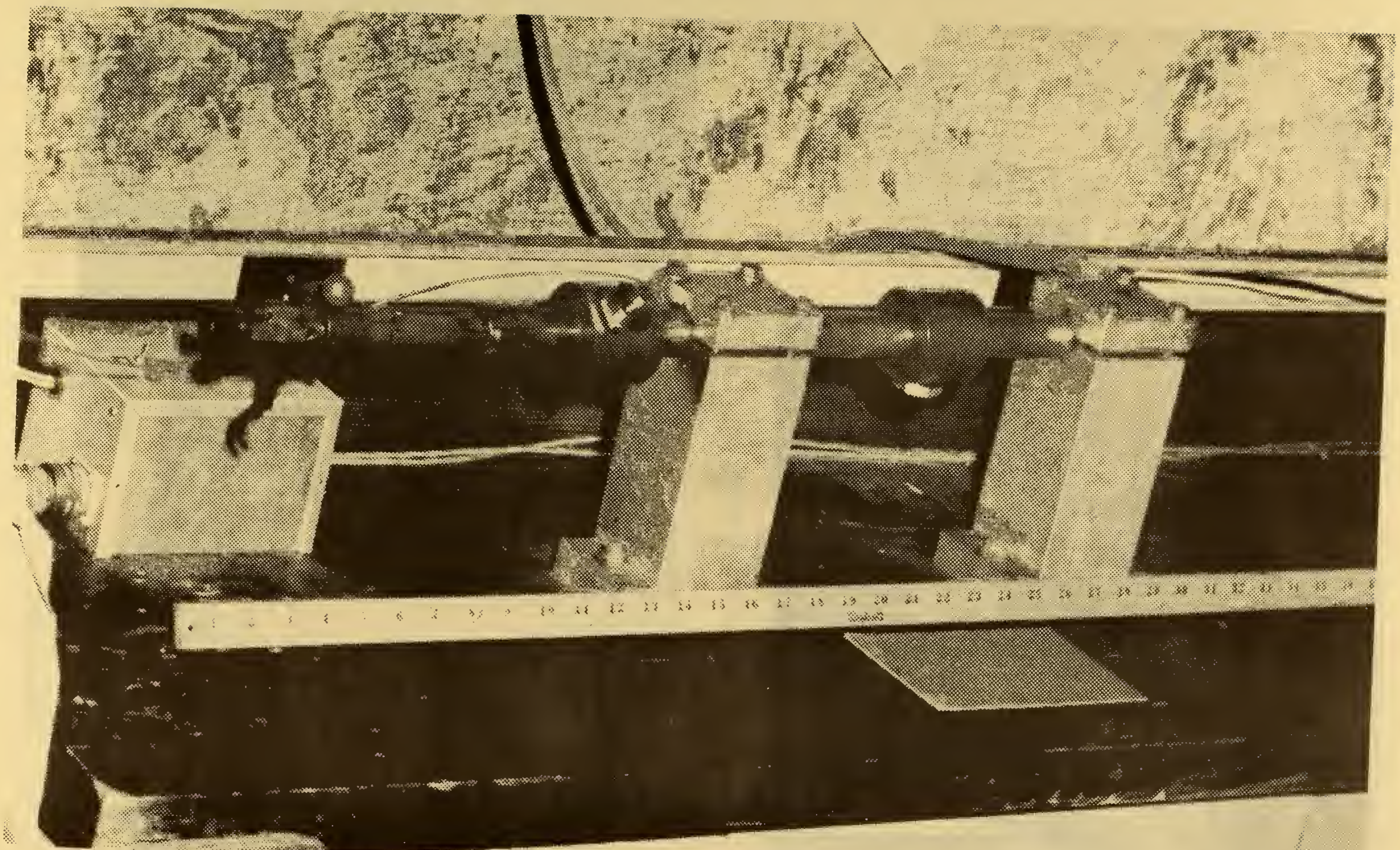


Figure 3. Modified rifle mounted on test bench

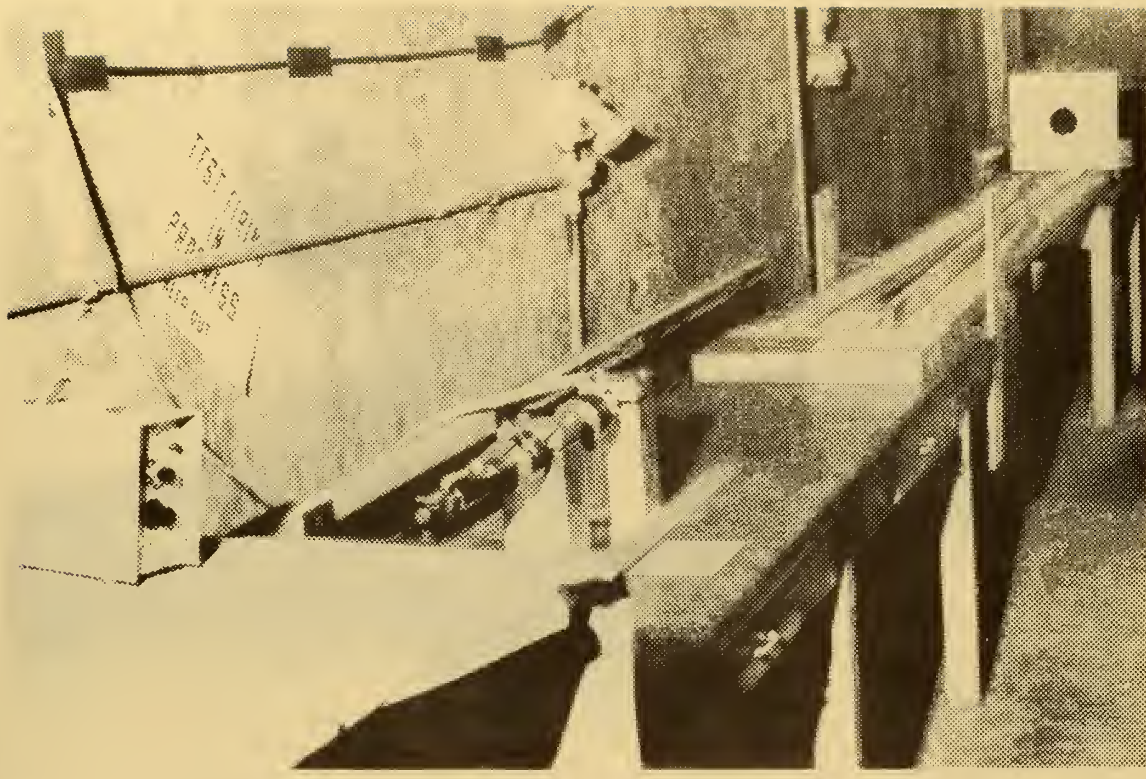


Figure 4. Indoor rifle range

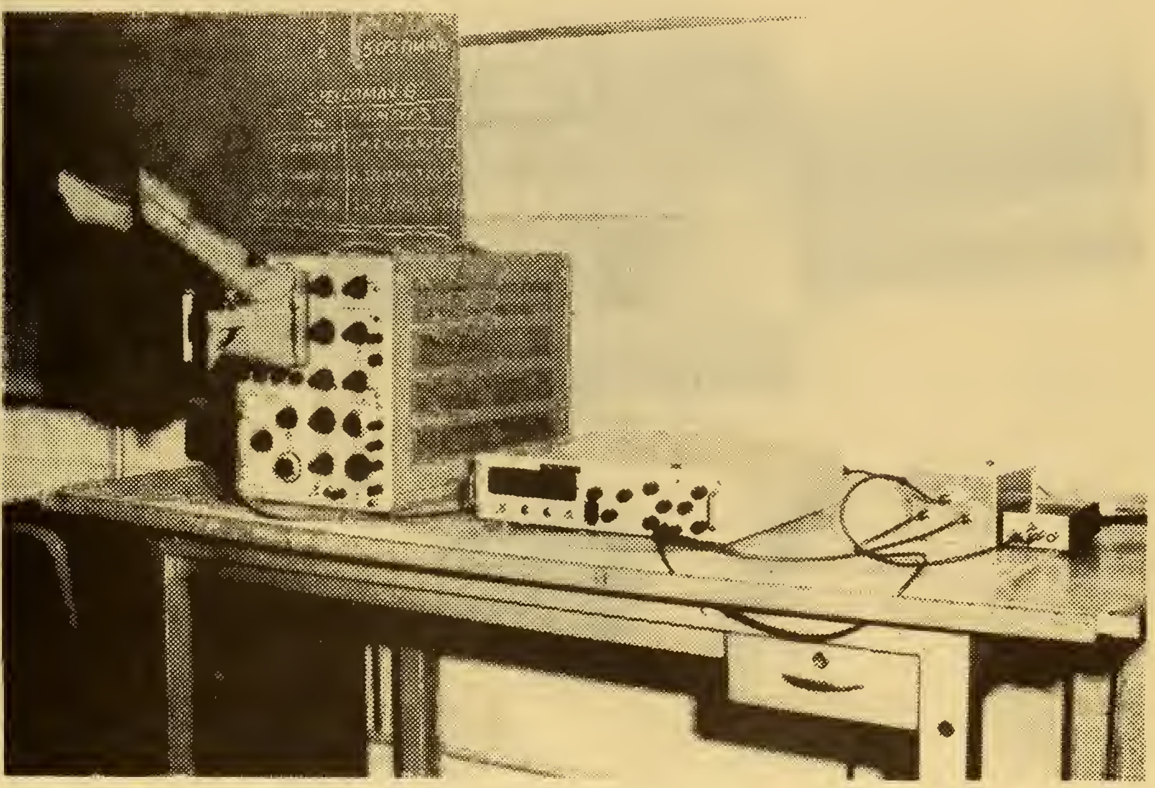


Figure 5. Electronic apparatus

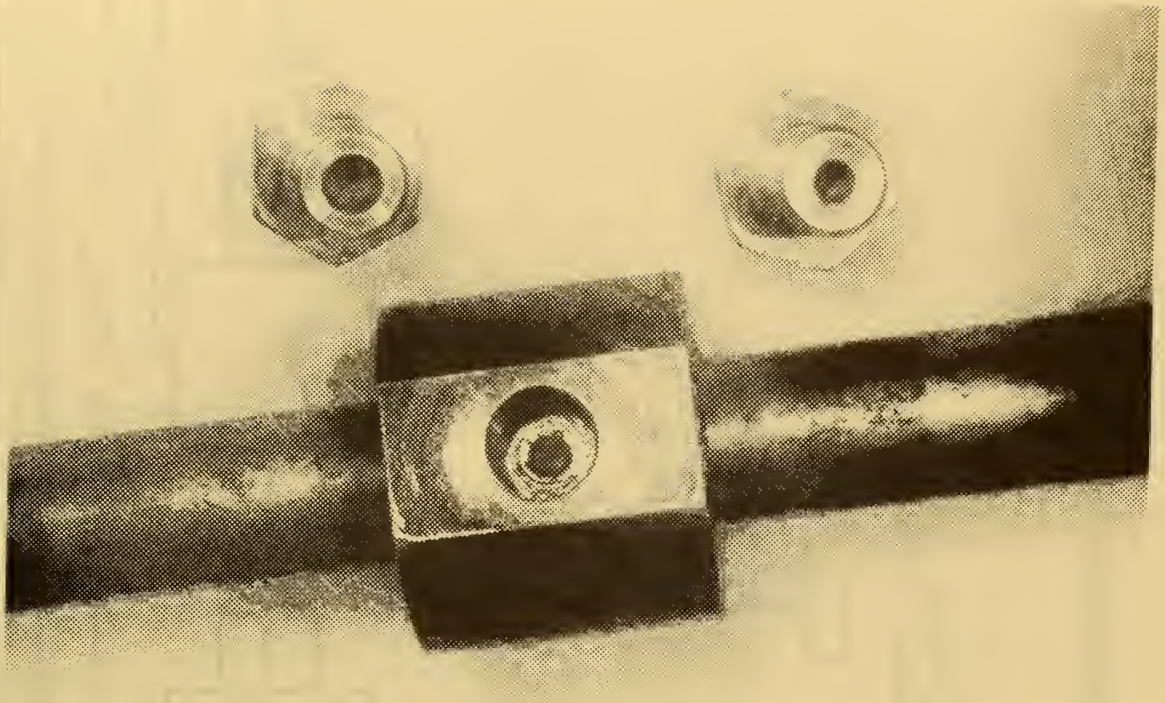


Figure 6. Secondary chambers and mount

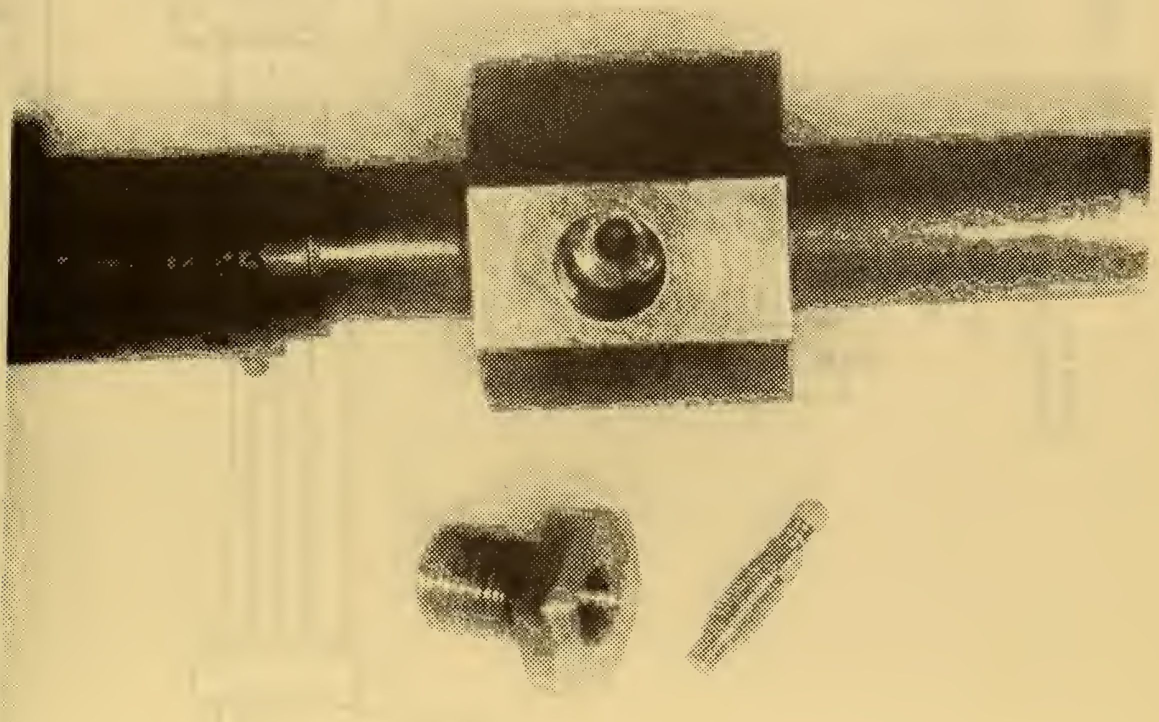
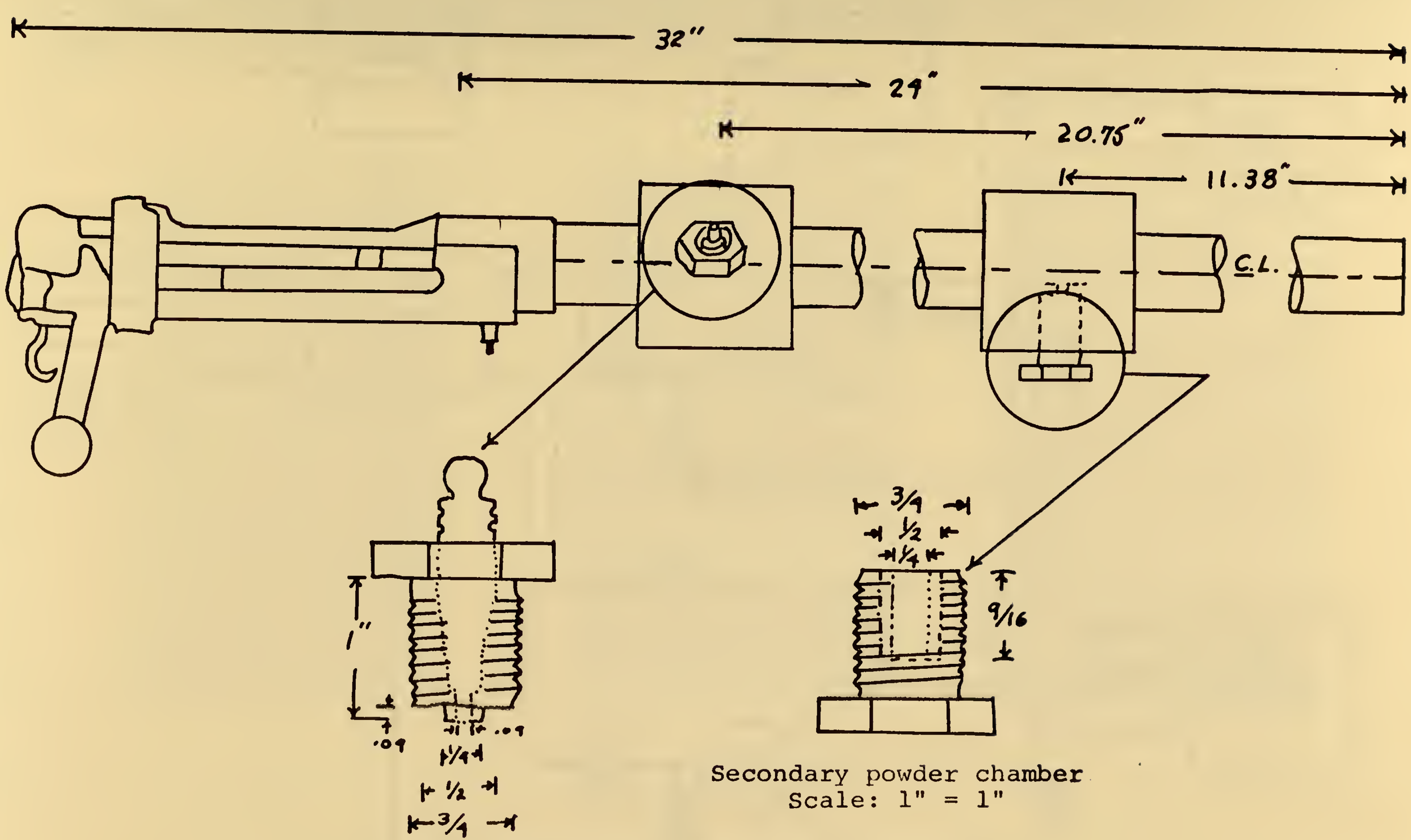


Figure 7. Transducer and mount



Transducer mount
Scale: 1" = 1"

Secondary powder chamber
Scale: 1" = 1"

Figure 8. Rifle adaptations

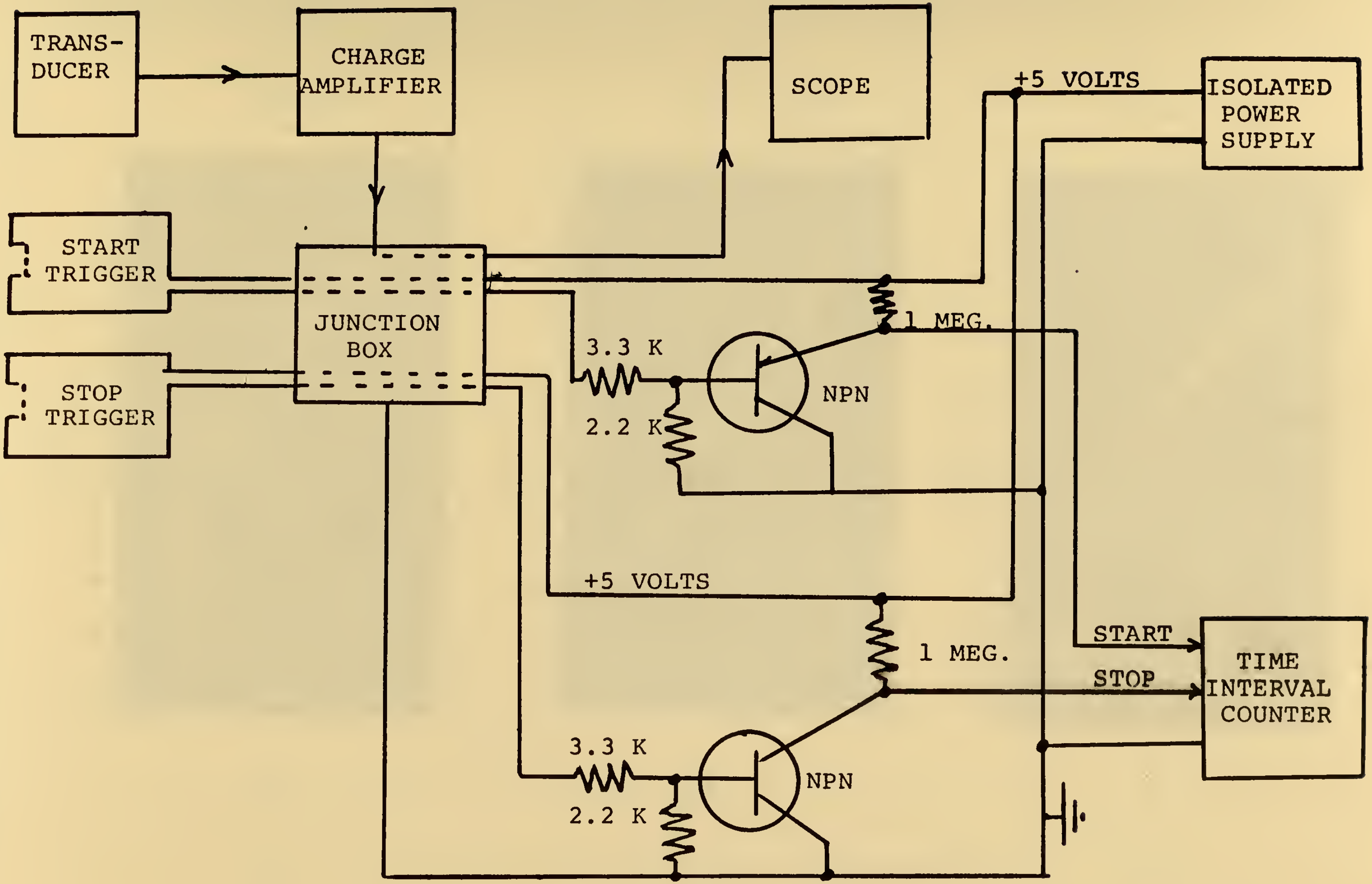
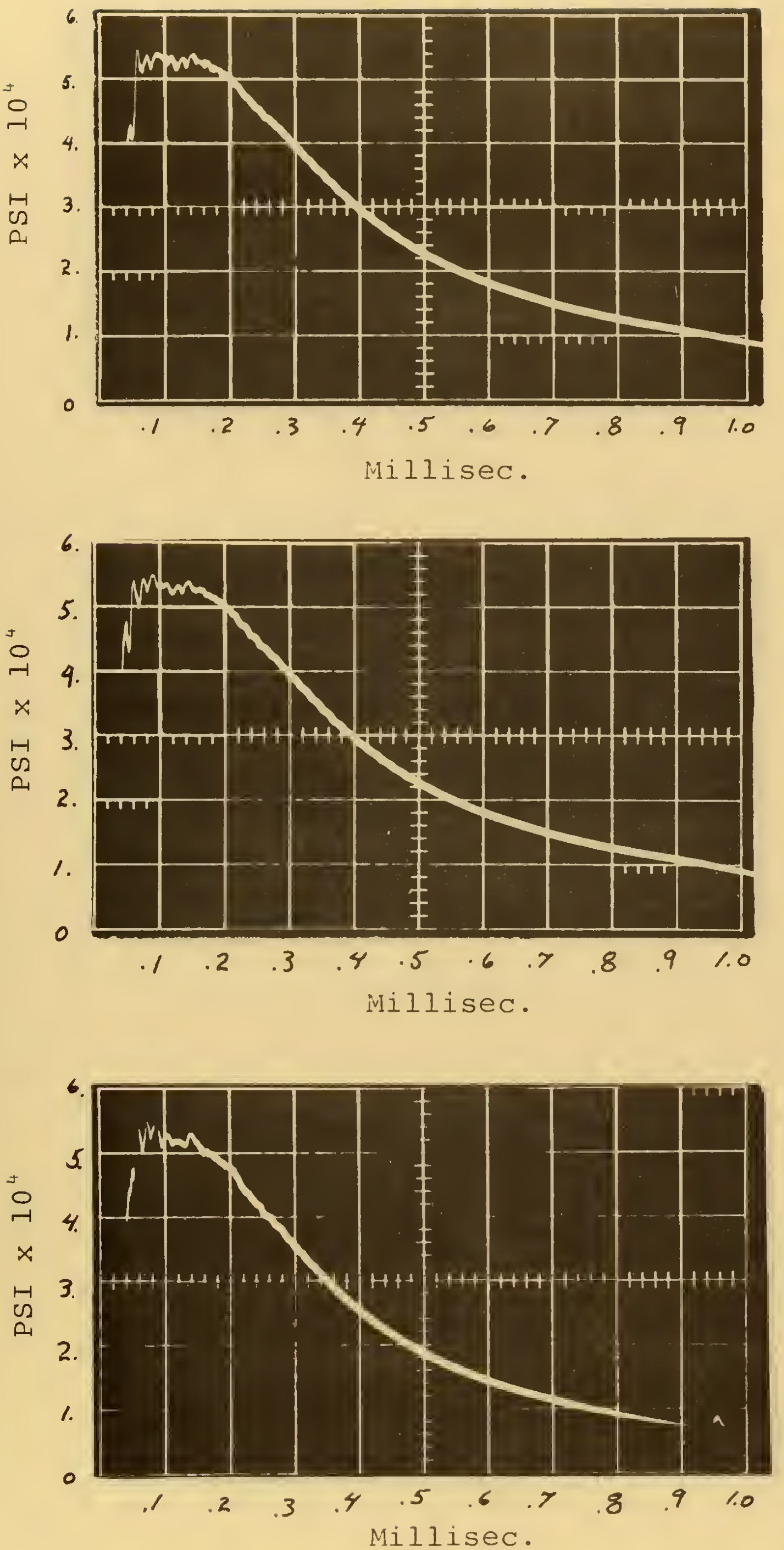


Figure 9. Wiring diagram

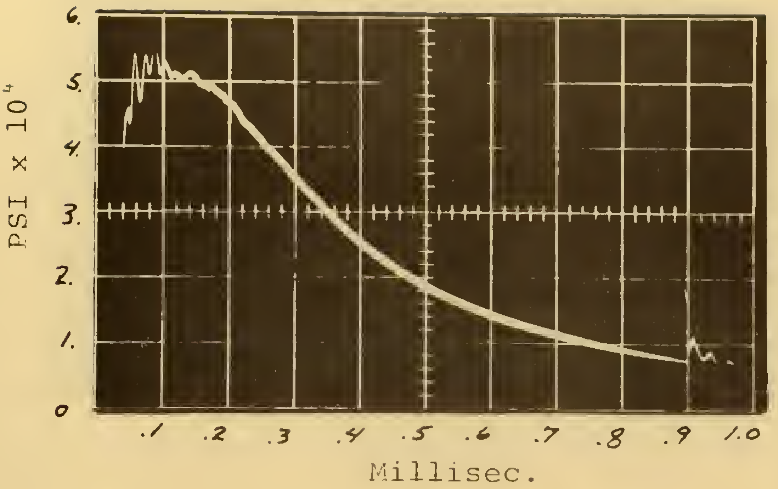


(a). 0.0 grains

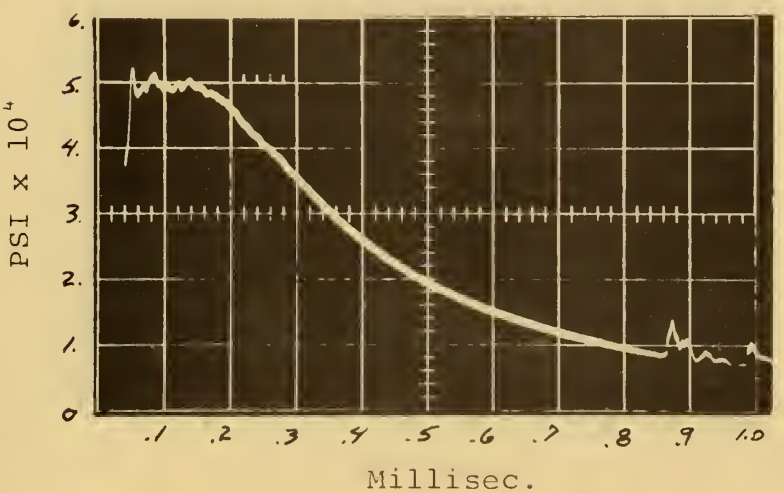
(b). 1.0 grains

(c). 2.0 grains

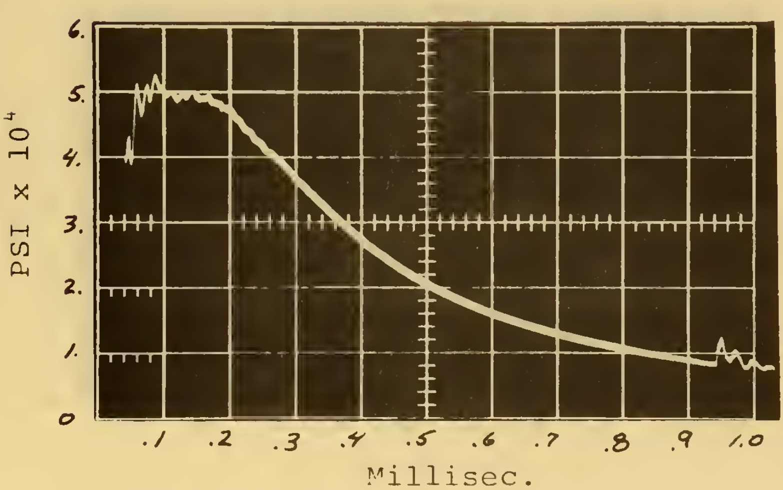
Figure 10: Pressure time traces for matched ammunition in 1.0 grain increments of secondary charge.



(d). 3.0 grains

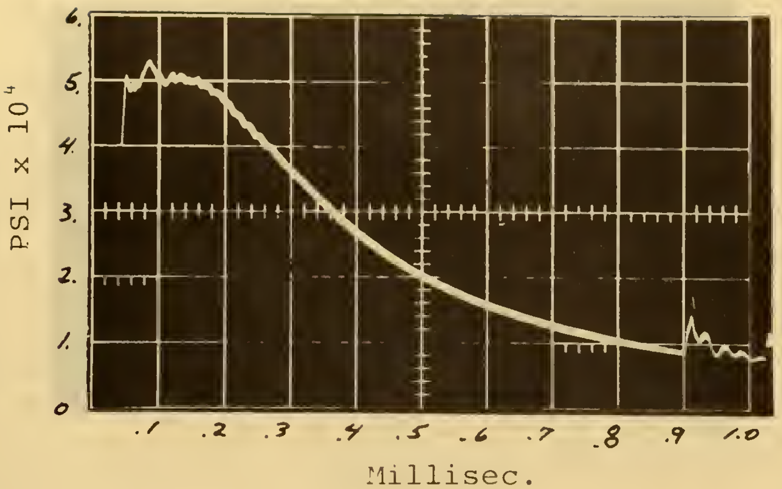


(e). 4.0 grains

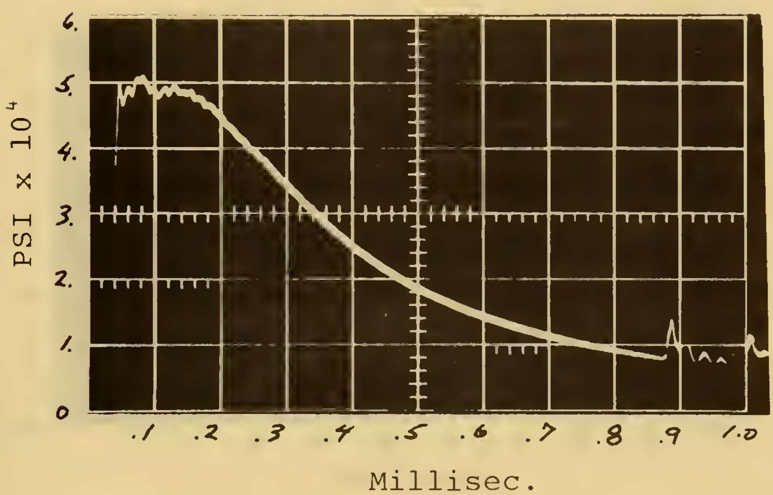


(f). 5.0 grains

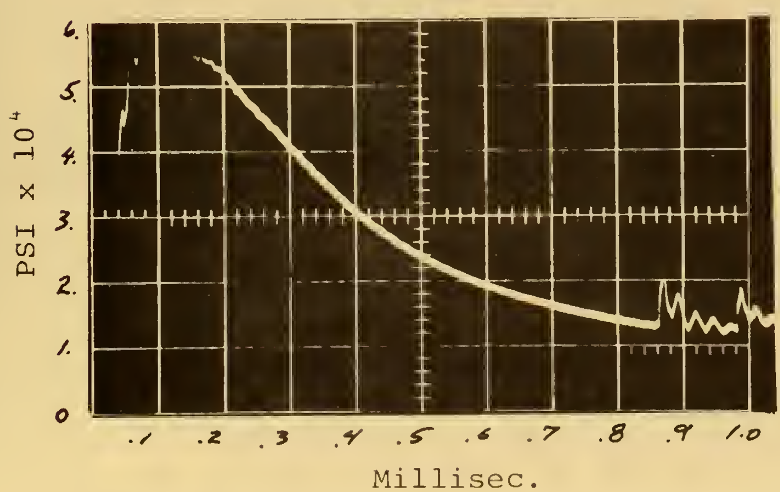
Figure 10: Pressure time traces for matched ammunition in 1.0 grain increments of secondary charge. (con't)



(g). 6.0 grains

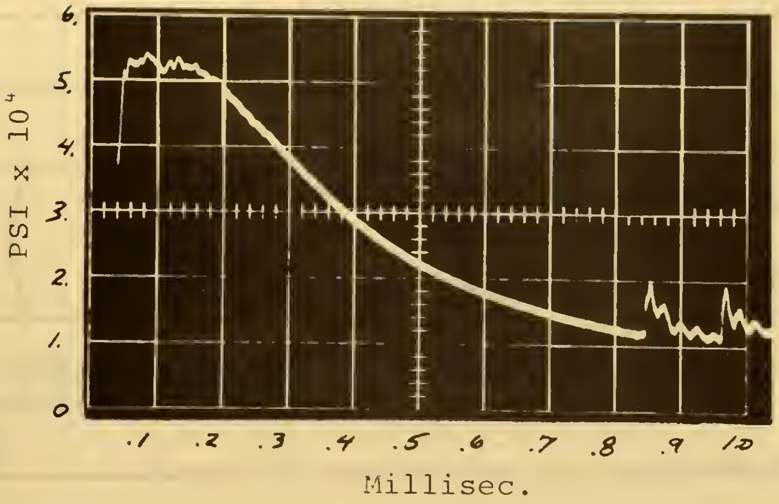


(h). 7.0 grains

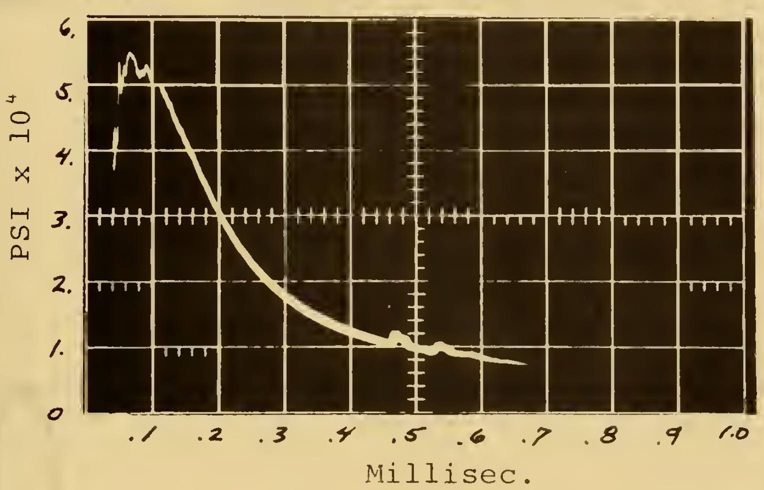


(i). 8.0 grains

Figure 10: Pressure time traces for matched ammunition in 1.0 grain increments of secondary charge. (con't)



(j). 9.0 grains



(k). 4.0 grains

Figure 10: Pressure time traces for matched ammunition in 1.0 grain increments of secondary charge. (con't)

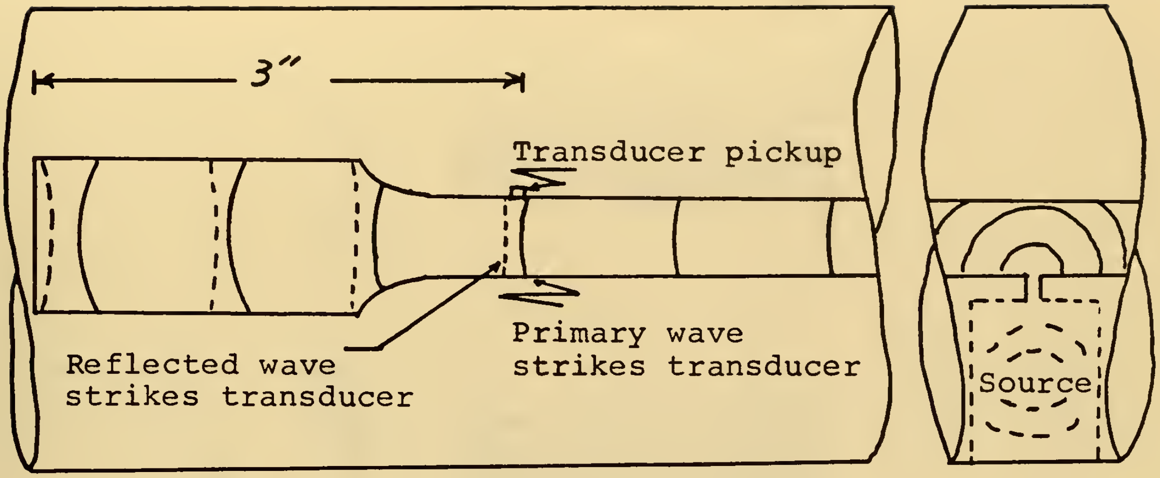


Figure 11(a). Diagram of breech end of rifle barrel depicting the primary wave front striking the transducer. The wave continues down the barrel, reflecting off the rear of the cartridge case, striking the transducer a second time.

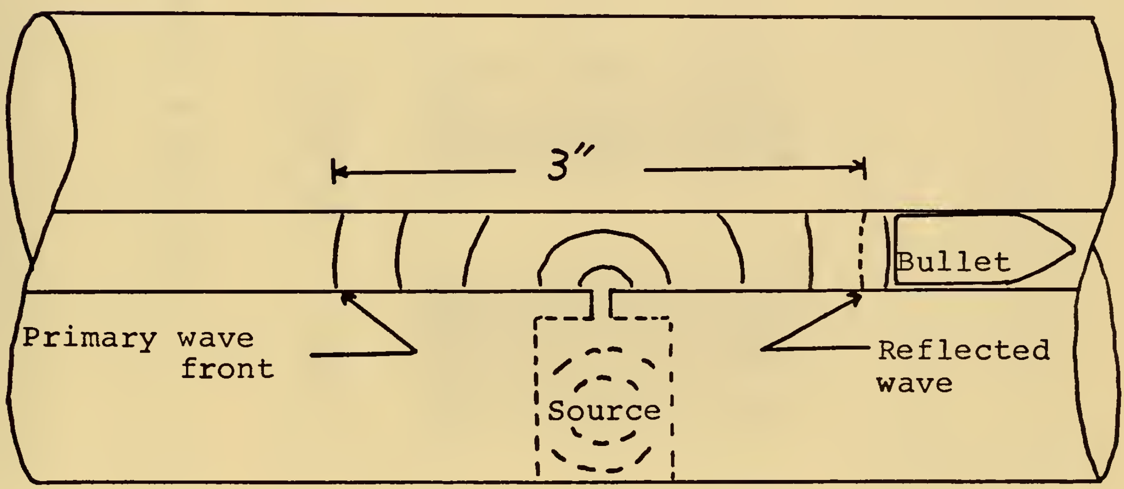


Figure 11(b). Diagram of rifle barrel depicting the interval between the primary wave front and the reflected wave off the bullet.

DATA SHEET DU PONT PISTOL POWCER # 5066.

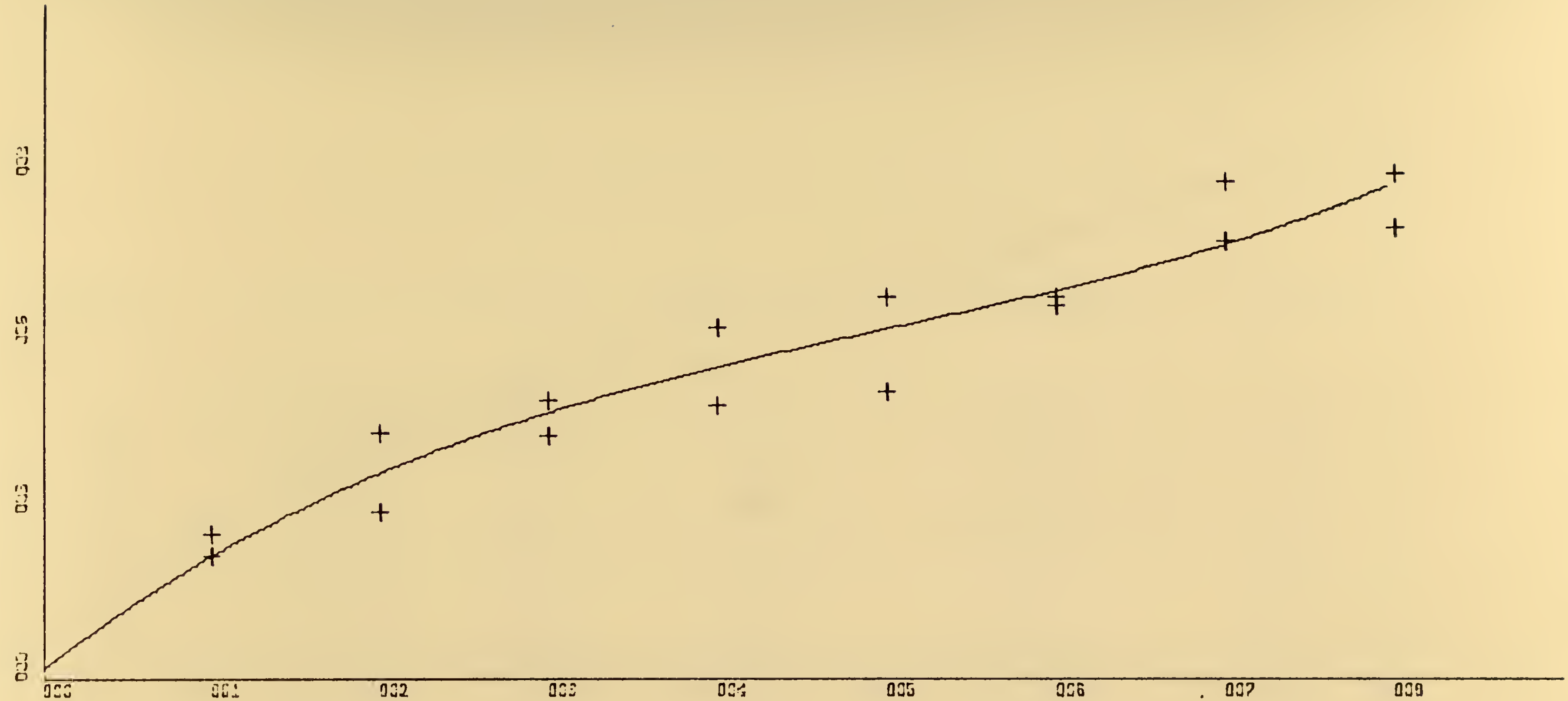
AMOUNT GRAINS	TIME SEC.	VELOCITY FT./SEC.	DELTA VEL. FT./SEC.	KINETIC ENERGY FT.-LBS.	DELTA K.E. FT.-LBS.
1.0	0.003574	2798.0	26.0	3129.2	58.2
1.0	0.003579	2794.1	22.1	3120.5	49.5
2.0	0.003551	2816.1	44.1	3169.8	98.8
2.0	0.003596	2801.9	29.9	3137.9	66.9
3.0	0.003544	2821.7	49.7	3182.4	111.4
3.0	0.003552	2815.3	43.3	3168.0	97.0
4.0	0.003545	2820.9	48.9	3180.6	109.6
4.0	0.003528	2834.5	62.5	3211.3	140.3
5.0	0.003521	2840.1	68.1	3224.0	153.0
5.0	0.003542	2823.3	51.3	3186.0	115.0
6.0	0.003521	2840.1	68.1	3224.0	153.0
6.0	0.003523	2838.5	66.5	3220.4	149.4
7.0	0.003496	2860.4	88.4	3270.3	199.3
7.0	0.003509	2849.8	77.8	3246.1	175.1
8.0	0.003494	2862.0	90.0	3274.0	203.0
8.0	0.003506	2852.3	80.3	3251.8	180.8

DATA SHEET DU PONT PISTOL POWDER # 5066
INTERPOLATED VALUES OF GRAINS OF POWDER VS. DELTA VEL. FPS

GRAINS	DELTA V	GRAINS	DELTA V	GRAINS	DELTA V	GRAINS	DELTA V
0.0	1.50	0.04	2.43	0.08	3.35	0.12	4.25
0.16	5.15	0.20	6.04	0.24	6.91	0.28	7.78
0.32	8.63	0.36	9.48	0.40	10.31	0.44	11.14
0.48	11.95	0.52	12.76	0.56	13.55	0.60	14.34
0.64	15.12	0.68	15.89	0.72	16.64	0.76	17.39
0.80	18.13	0.84	18.86	0.88	19.59	0.92	20.30
0.96	21.00	1.00	21.70	1.04	22.39	1.08	23.07
1.12	23.74	1.16	24.40	1.20	25.05	1.24	25.70
1.28	26.33	1.32	26.96	1.36	27.58	1.40	28.20
1.44	28.80	1.48	29.40	1.52	29.99	1.56	30.58
1.60	31.15	1.64	31.72	1.68	32.28	1.72	32.84
1.76	33.38	1.80	33.92	1.84	34.46	1.88	34.98
1.92	35.50	1.96	36.02	2.00	36.52	2.04	37.02
2.08	37.52	2.12	38.00	2.16	38.48	2.20	38.96
2.24	39.43	2.28	39.89	2.32	40.35	2.36	40.80
2.40	41.25	2.44	41.69	2.48	42.12	2.52	42.55
2.56	42.98	2.60	43.39	2.64	43.81	2.68	44.22
2.72	44.62	2.76	45.02	2.80	45.41	2.84	45.80
2.88	46.19	2.92	46.57	2.96	46.94	3.00	47.31
3.04	47.68	3.08	48.04	3.12	48.40	3.16	48.75
3.20	49.11	3.24	49.45	3.28	49.79	3.32	50.13
3.36	50.47	3.40	50.80	3.44	51.13	3.48	51.46
3.52	51.78	3.56	52.10	3.60	52.41	3.64	52.72
3.68	53.03	3.72	53.34	3.76	53.65	3.80	53.95
3.84	54.25	3.88	54.54	3.92	54.84	3.96	55.13
4.00	55.42	4.04	55.70	4.08	55.99	4.12	56.27
4.16	56.55	4.20	56.83	4.24	57.11	4.28	57.39
4.32	57.66	4.36	57.94	4.40	58.21	4.44	58.48
4.48	58.75	4.52	59.02	4.56	59.28	4.60	59.55
4.64	59.82	4.68	60.08	4.72	60.35	4.76	60.61
4.80	60.87	4.84	61.13	4.88	61.40	4.92	61.66
4.96	61.92	5.00	62.18	5.04	62.44	5.08	62.71
5.12	62.97	5.16	63.23	5.20	63.49	5.24	63.76
5.28	64.02	5.32	64.28	5.36	64.55	5.40	64.81
5.44	65.08	5.48	65.35	5.52	65.62	5.56	65.89
5.60	66.16	5.64	66.43	5.68	66.70	5.72	66.98
5.76	67.25	5.80	67.53	5.84	67.81	5.88	68.09
5.92	68.38	5.96	68.66	6.00	68.95	6.04	69.24
6.08	69.53	6.12	69.83	6.16	70.13	6.20	70.43
6.24	70.73	6.28	71.03	6.32	71.34	6.36	71.65
6.40	71.96	6.44	72.28	6.48	72.60	6.52	72.92
6.56	73.25	6.60	73.58	6.64	73.91	6.68	74.25
6.72	74.59	6.76	74.93	6.80	75.28	6.84	75.63
6.88	75.98	6.92	76.34	6.96	76.71	7.00	77.07
7.04	77.44	7.08	77.82	7.12	78.20	7.16	78.59
7.20	78.98	7.24	79.37	7.28	79.77	7.32	80.18
7.36	80.59	7.40	81.00	7.44	81.42	7.48	81.85
7.52	82.28	7.56	82.71	7.60	83.15	7.64	83.60
7.68	84.05	7.72	84.51	7.76	84.98	7.80	85.45
7.84	85.92	7.88	86.40	7.92	86.89	7.96	87.39

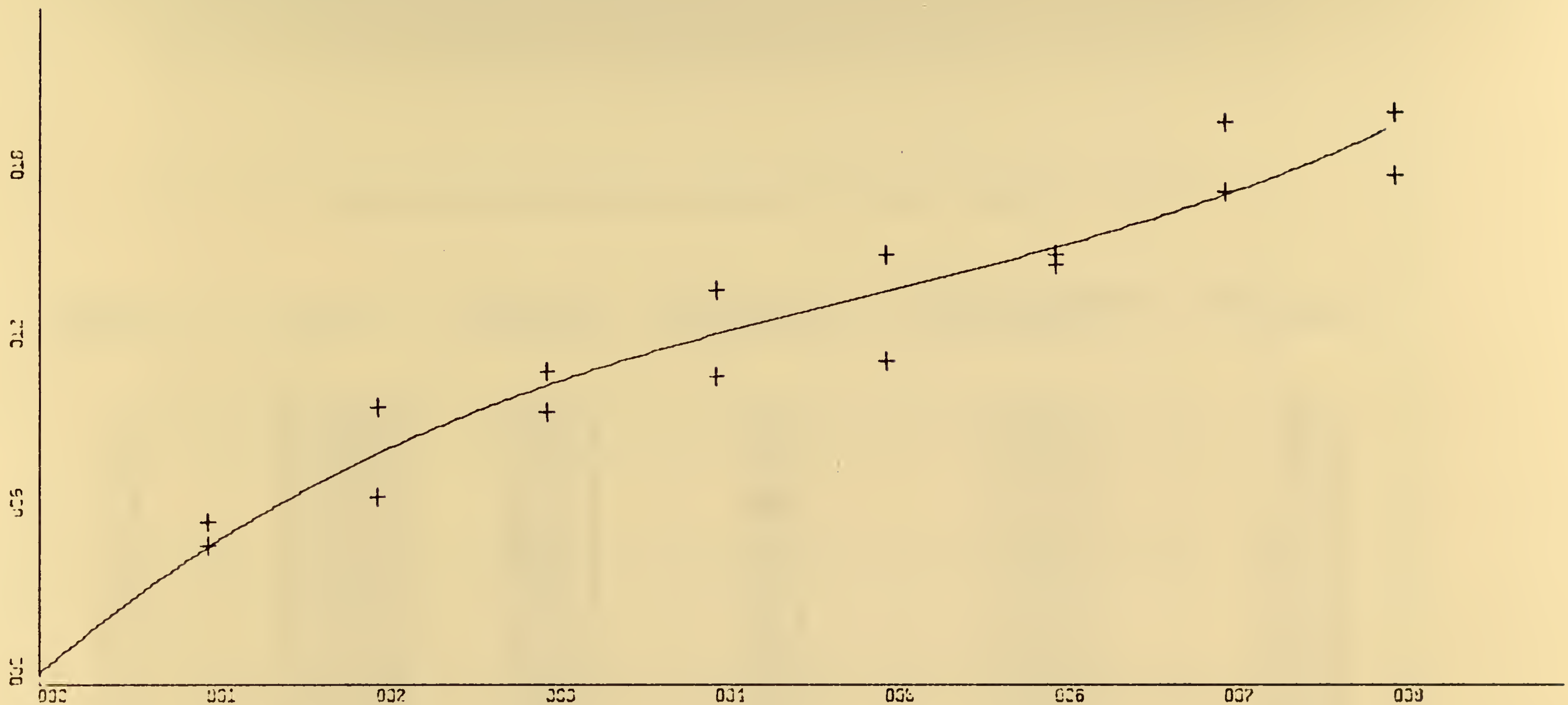
DATA SHEET DU PONT PISTOL POWDER # 5066
INTERPOLATED VALUES GRAINS OF POWDER VS. DELTA K.E. FT-LBS

GRAINS	DEL.K E	GRAINS	DEL.K E	GRAINS	DEL.K E	GRAINS	DEL.K E
0.0	3.35	0.04	5.43	0.08	7.48	0.12	9.51
0.16	11.52	0.20	13.50	0.24	15.46	0.28	17.40
0.32	19.31	0.36	21.20	0.40	23.07	0.44	24.92
0.48	26.74	0.52	28.55	0.56	30.33	0.60	32.09
0.64	33.83	0.68	35.55	0.72	37.25	0.76	38.93
0.80	40.58	0.84	42.22	0.88	43.84	0.92	45.43
0.96	47.01	1.00	48.57	1.04	50.11	1.08	51.63
1.12	53.13	1.16	54.61	1.20	56.08	1.24	57.52
1.28	58.95	1.32	60.36	1.36	61.75	1.40	63.13
1.44	64.49	1.48	65.83	1.52	67.15	1.56	68.46
1.60	69.75	1.64	71.02	1.68	72.28	1.72	73.52
1.76	74.75	1.80	75.96	1.84	77.15	1.88	78.34
1.92	79.50	1.96	80.65	2.00	81.79	2.04	82.91
2.08	84.02	2.12	85.11	2.16	86.19	2.20	87.26
2.24	88.31	2.28	89.35	2.32	90.38	2.36	91.39
2.40	92.39	2.44	93.38	2.48	94.36	2.52	95.32
2.56	96.27	2.60	97.22	2.64	98.14	2.68	99.06
2.72	99.97	2.76	100.87	2.80	101.75	2.84	102.63
2.88	103.49	2.92	104.35	2.96	105.19	3.00	106.03
3.04	106.85	3.08	107.67	3.12	108.47	3.16	109.27
3.20	110.06	3.24	110.84	3.28	111.61	3.32	112.38
3.36	113.13	3.40	113.88	3.44	114.62	3.48	115.36
3.52	116.08	3.56	116.80	3.60	117.51	3.64	118.22
3.68	118.92	3.72	119.61	3.76	120.30	3.80	120.98
3.84	121.65	3.88	122.32	3.92	122.99	3.96	123.65
4.00	124.30	4.04	124.95	4.08	125.59	4.12	126.23
4.16	126.87	4.20	127.50	4.24	128.13	4.28	128.76
4.32	129.38	4.36	130.00	4.40	130.62	4.44	131.23
4.48	131.84	4.52	132.45	4.56	133.05	4.60	133.66
4.64	134.26	4.68	134.86	4.72	135.46	4.76	136.06
4.80	136.65	4.84	137.25	4.88	137.84	4.92	138.44
4.96	139.03	5.00	139.63	5.04	140.22	5.08	140.82
5.12	141.41	5.16	142.01	5.20	142.60	5.24	143.20
5.28	143.80	5.32	144.40	5.36	145.00	5.40	145.61
5.44	146.22	5.48	146.82	5.52	147.43	5.56	148.05
5.60	148.66	5.64	149.28	5.68	149.91	5.72	150.53
5.76	151.16	5.80	151.80	5.84	152.43	5.88	153.07
5.92	153.72	5.96	154.37	6.00	155.03	6.04	155.69
6.08	156.35	6.12	157.02	6.16	157.70	6.20	158.38
6.24	159.07	6.28	159.76	6.32	160.46	6.36	161.17
6.40	161.88	6.44	162.60	6.48	163.33	6.52	164.06
6.56	164.80	6.60	165.55	6.64	166.31	6.68	167.08
6.72	167.85	6.76	168.63	6.80	169.42	6.84	170.22
6.88	171.03	6.92	171.85	6.96	172.67	7.00	173.51
7.04	174.36	7.08	175.21	7.12	176.08	7.16	176.96
7.20	177.84	7.24	178.74	7.28	179.65	7.32	180.57
7.36	181.50	7.40	182.45	7.44	183.40	7.48	184.37
7.52	185.35	7.56	186.34	7.60	187.34	7.64	188.36
7.68	189.38	7.72	190.43	7.76	191.48	7.80	192.55
7.84	193.63	7.88	194.73	7.92	195.84	7.96	196.96



X-SCALE=1.00E+00 UNITS INCH.
Y-SCALE=3.00E+01 UNITS INCH.

VELOCITY INCREASE FPS VS. GRAINS
DU PONT PISTOL POWDER V0 = 2772



X-SCALE 1.00E+00 UNITS INCH.
Y-SCALE 6.00E+01 UNITS INCH.
KINETIC ENERGY INCREASE FT-LBS VS. GRAINS
DU PØNT PISTØL PØWDER K.E. ZERØ = 3071

DATA SHEET HERCULES BULLSEYE PISTOL POWDER

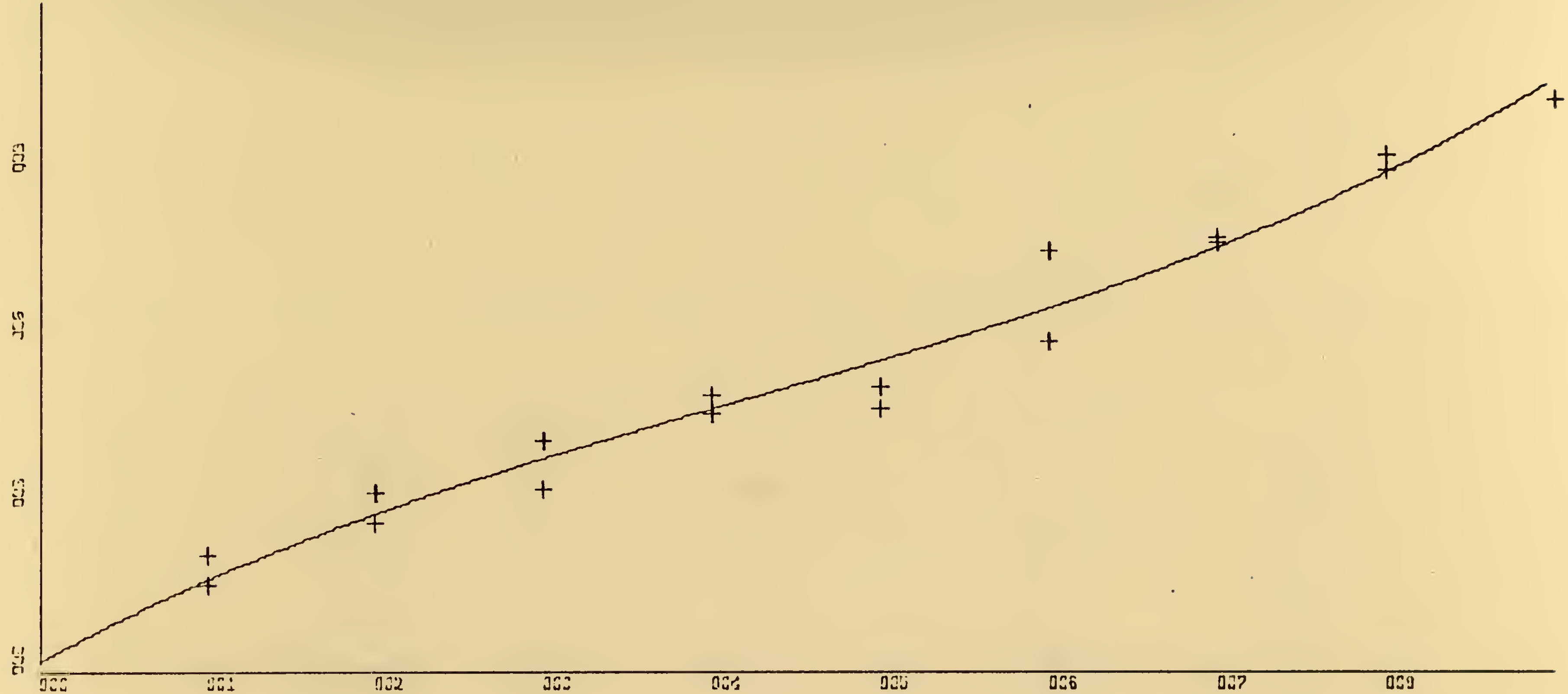
AMOUNT GRAINS	TIME SEC.	VELOCITY FT./SEC.	DELTA VEL. FT./SEC.	KINETIC ENERGY FT.-LBS.	DELTA K.E. FT.-LBS.
1.0	0.003580	2793.3	21.3	3118.7	47.7
1.0	0.003587	2787.8	15.8	3106.4	35.4
2.0	0.003573	2798.8	26.8	3131.0	60.0
2.0	0.003566	2804.3	32.3	3143.3	72.3
3.0	0.003565	2805.0	33.0	3144.8	73.8
3.0	0.003554	2813.7	41.7	3164.4	93.4
4.0	0.003544	2821.7	49.7	3182.4	111.4
4.0	0.003548	2818.5	46.5	3175.2	104.2
5.0	0.003547	2819.3	47.3	3177.0	106.0
5.0	0.003542	2823.3	51.3	3186.0	115.0
6.0	0.003532	2831.3	59.3	3204.1	133.1
6.0	0.003512	2847.4	75.4	3240.6	169.6
7.0	0.003510	2849.0	77.0	3244.3	173.3
7.0	0.003509	2849.8	77.8	3246.1	175.1
8.0	0.003494	2862.0	90.0	3274.0	203.0
8.0	0.003491	2864.5	92.5	3279.7	208.7
9.0	0.003479	2874.4	102.4	3302.4	231.4
9.0	0.003475	2877.7	105.7	3310.0	239.0

DATA SHEET HERCULES BULLSEYE PISC L POWDER
INTERPOLATED VALUES OF GRAINS POWDER VS. DELTA VEL. FPS

GRAINS	DELTA V	GRAINS	DELTA V	GRAINS	DELTA V	GRAINS	DELTA V
0.0	1.80	0.04	2.53	0.09	3.26	0.13	3.98
0.18	4.69	0.22	5.39	0.27	6.09	0.31	6.77
0.36	7.46	0.40	8.13	0.45	8.80	0.49	9.46
0.54	10.12	0.58	10.77	0.63	11.41	0.67	12.04
0.72	12.67	0.76	13.30	0.81	13.91	0.85	14.53
0.90	15.13	0.94	15.73	0.99	16.32	1.03	16.91
1.08	17.49	1.12	18.07	1.17	18.64	1.21	19.21
1.26	19.77	1.30	20.32	1.35	20.87	1.39	21.42
1.44	21.96	1.48	22.49	1.53	23.02	1.57	23.55
1.62	24.07	1.66	24.59	1.71	25.10	1.75	25.61
1.80	26.11	1.84	26.61	1.89	27.10	1.93	27.59
1.98	28.08	2.02	28.56	2.07	29.04	2.11	29.52
2.16	29.99	2.20	30.45	2.25	30.92	2.29	31.38
2.34	31.83	2.38	32.29	2.43	32.74	2.47	33.19
2.52	33.63	2.56	34.07	2.61	34.51	2.65	34.94
2.70	35.38	2.74	35.81	2.79	36.23	2.83	36.66
2.88	37.08	2.92	37.50	2.97	37.92	3.01	38.33
3.06	38.75	3.10	39.16	3.15	39.57	3.19	39.98
3.24	40.38	3.28	40.79	3.33	41.19	3.37	41.59
3.42	41.99	3.46	42.39	3.51	42.78	3.55	43.18
3.60	43.57	3.64	43.96	3.69	44.36	3.73	44.75
3.78	45.14	3.82	45.53	3.87	45.91	3.91	46.30
3.96	46.69	4.00	47.08	4.05	47.46	4.09	47.85
4.14	48.24	4.18	48.62	4.23	49.01	4.27	49.40
4.32	49.78	4.36	50.17	4.41	50.55	4.45	50.94
4.50	51.33	4.54	51.72	4.59	52.11	4.63	52.49
4.68	52.88	4.72	53.27	4.77	53.67	4.81	54.06
4.86	54.45	4.90	54.85	4.95	55.24	4.99	55.64
5.04	56.04	5.08	56.44	5.13	56.84	5.17	57.25
5.22	57.65	5.26	58.06	5.31	58.47	5.35	58.88
5.40	59.29	5.44	59.70	5.49	60.12	5.53	60.54
5.58	60.96	5.62	61.39	5.67	61.81	5.71	62.24
5.76	62.67	5.80	63.11	5.85	63.54	5.89	63.99
5.94	64.43	5.98	64.87	6.03	65.32	6.07	65.78
6.12	66.23	6.16	66.69	6.21	67.15	6.25	67.62
6.30	68.09	6.34	68.56	6.39	69.04	6.43	69.52
6.48	70.01	6.52	70.50	6.57	70.99	6.61	71.49
6.66	71.99	6.70	72.50	6.75	73.01	6.79	73.52
6.84	74.04	6.88	74.56	6.93	75.09	6.97	75.63
7.02	76.17	7.06	76.71	7.11	77.26	7.15	77.81
7.20	78.37	7.24	78.93	7.29	79.50	7.33	80.08
7.38	80.66	7.42	81.25	7.47	81.84	7.51	82.44
7.56	83.04	7.60	83.65	7.65	84.26	7.69	84.89
7.74	85.51	7.78	86.15	7.83	86.79	7.87	87.43
7.92	88.09	7.96	88.75	8.01	89.41	8.05	90.09
8.10	90.77	8.14	91.45	8.19	92.15	8.23	92.85
8.28	93.56	8.32	94.27	8.37	94.99	8.41	95.72
8.46	96.46	8.50	97.21	8.55	97.96	8.59	98.72
8.64	99.49	8.68	100.26	8.73	101.05	8.77	101.84
8.82	102.64	8.86	103.44	8.91	104.26	8.95	105.09

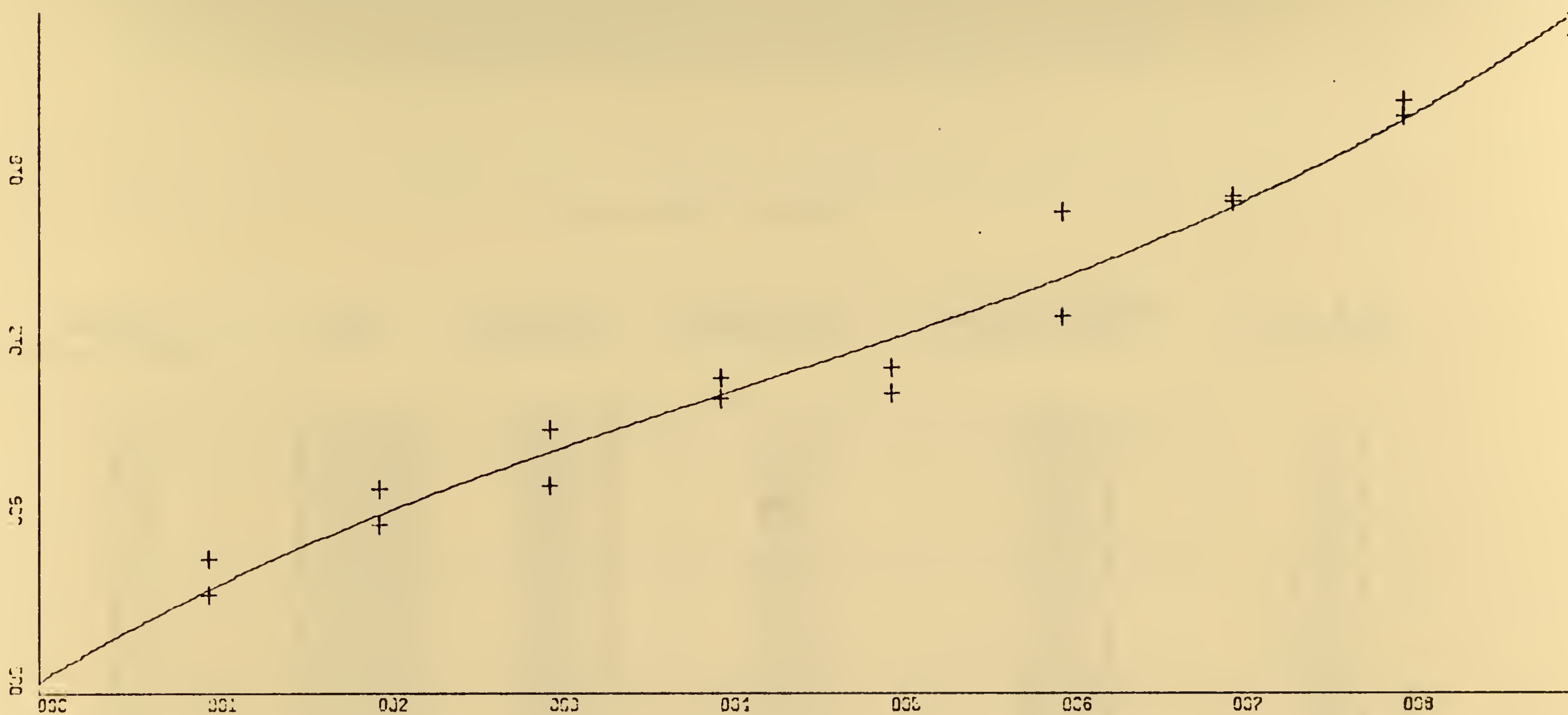
DATA SHEET HERCULES BULLSEYE PISCL POWDER
INTERPOLATED VALUES GRAINS POWDER VS. DELTA K.E. FT-LBS

GRAINS	CEL.K E	GRAINS	DEL.K E	GRAINS	DEL.K E	GRAINS	DEL.K E
0.0	4.02	0.04	5.64	0.09	7.25	0.13	8.84
0.18	10.41	0.22	11.97	0.27	13.51	0.31	15.04
0.36	16.55	0.40	18.05	0.45	19.53	0.49	21.00
0.54	22.46	0.58	23.90	0.63	25.32	0.67	26.73
0.72	28.13	0.76	29.52	0.81	30.89	0.85	32.25
0.90	33.59	0.94	34.93	0.99	36.25	1.03	37.55
1.08	38.85	1.12	40.13	1.17	41.40	1.21	42.66
1.26	43.91	1.30	45.15	1.35	46.37	1.39	47.59
1.44	48.79	1.48	49.99	1.53	51.17	1.57	52.34
1.62	53.50	1.66	54.65	1.71	55.80	1.75	56.93
1.80	58.05	1.84	59.17	1.89	60.27	1.93	61.37
1.98	62.46	2.02	63.53	2.07	64.61	2.11	65.67
2.16	66.72	2.20	67.77	2.25	68.81	2.29	69.84
2.34	70.86	2.38	71.88	2.43	72.89	2.47	73.89
2.52	74.89	2.56	75.88	2.61	76.86	2.65	77.84
2.70	78.81	2.74	79.78	2.79	80.74	2.83	81.70
2.88	82.65	2.92	83.59	2.97	84.53	3.01	85.47
3.06	86.40	3.10	87.33	3.15	88.25	3.19	89.17
3.24	90.08	3.28	90.99	3.33	91.90	3.37	92.81
3.42	93.71	3.46	94.61	3.51	95.50	3.55	96.40
3.60	97.29	3.64	98.18	3.69	99.06	3.73	99.95
3.78	100.83	3.82	101.71	3.87	102.59	3.91	103.47
3.96	104.35	4.00	105.23	4.05	106.11	4.09	106.98
4.14	107.86	4.18	108.74	4.23	109.61	4.27	110.49
4.32	111.37	4.36	112.25	4.41	113.12	4.45	114.00
4.50	114.89	4.54	115.77	4.59	116.65	4.63	117.54
4.68	118.42	4.72	119.31	4.77	120.21	4.81	121.10
4.86	122.00	4.90	122.90	4.95	123.80	4.99	124.70
5.04	125.61	5.08	126.52	5.13	127.44	5.17	128.36
5.22	129.28	5.26	130.21	5.31	131.14	5.35	132.08
5.40	133.02	5.44	133.97	5.49	134.92	5.53	135.87
5.58	136.84	5.62	137.80	5.67	138.78	5.71	139.76
5.76	140.74	5.80	141.73	5.85	142.73	5.89	143.74
5.94	144.75	5.98	145.77	6.03	146.79	6.07	147.82
6.12	148.86	6.16	149.91	6.21	150.97	6.25	152.03
6.30	153.11	6.34	154.19	6.39	155.28	6.43	156.37
6.48	157.48	6.52	158.60	6.57	159.72	6.61	160.86
6.66	162.00	6.70	163.16	6.75	164.32	6.79	165.49
6.84	166.68	6.88	167.87	6.93	169.08	6.97	170.30
7.02	171.52	7.06	172.76	7.11	174.01	7.15	175.28
7.20	176.55	7.24	177.84	7.29	179.13	7.33	180.44
7.38	181.77	7.42	183.10	7.47	184.45	7.51	185.81
7.56	187.19	7.60	188.57	7.65	189.97	7.69	191.39
7.74	192.82	7.78	194.26	7.83	195.72	7.87	197.19
7.92	198.68	7.96	200.18	8.01	201.69	8.05	203.22
8.10	204.77	8.14	206.33	8.19	207.91	8.23	209.50
8.28	211.11	8.32	212.73	8.37	214.38	8.41	216.03
8.46	217.71	8.50	219.40	8.55	221.11	8.59	222.84
8.64	224.58	8.68	226.34	8.73	228.12	8.77	229.91
8.82	231.73	8.86	233.56	8.91	235.41	8.95	237.28



X-SCALE=1.00E+00 UNITS INCH.
Y-SCALE=3.00E+01 UNITS INCH.

VELOCITY INCREASE FPS VS. GRAINS
BULLSEYE PISTOL POWDER VO = 2772



X-SCALE=1.00E+00 UNITS INCH.
Y-SCALE=6.00E+01 UNITS INCH.

KINETIC ENERGY INCREASE FT-LBS VS GRAINS
BULLSEYE PISTØL PØWDER K.E. 0 = 3071

DATA SHEET LIQUID A

AMOUNT MILLILITER	TIME SEC.	VELOCITY FT./SEC.	DELTA VEL. FT./SEC.	KINETIC ENERGY FT.-LBS.	DELTA K.E. FT.-LBS.
0.1	0.003605	2773.9	1.9	3075.2	4.2
0.1	0.003596	2780.9	8.9	3090.8	19.8
0.2	0.003583	2791.0	19.0	3113.2	42.2
0.2	0.003587	2787.8	15.8	3106.1	35.1
0.3	0.003559	2809.8	37.8	3155.3	84.3
0.3	0.003577	2795.6	23.6	3123.5	52.5
0.4	0.003545	2820.1	48.1	3178.5	107.5
0.4	0.003550	2816.9	44.9	3171.3	100.3
0.5	0.003527	2835.3	63.3	3212.9	141.9
0.5	0.003533	2830.5	58.5	3202.0	131.0
0.6	0.003511	2848.2	76.2	3242.2	171.2
0.6	0.003515	2844.9	72.9	3234.7	163.7
0.7	0.003510	2849.0	77.0	3244.0	173.0
0.7	0.003496	2860.4	88.4	3270.0	199.0
0.8	0.003486	2868.7	96.7	3289.0	218.0
0.8	0.003498	2858.8	86.8	3266.3	195.3

DATA SHEET LIQUID A

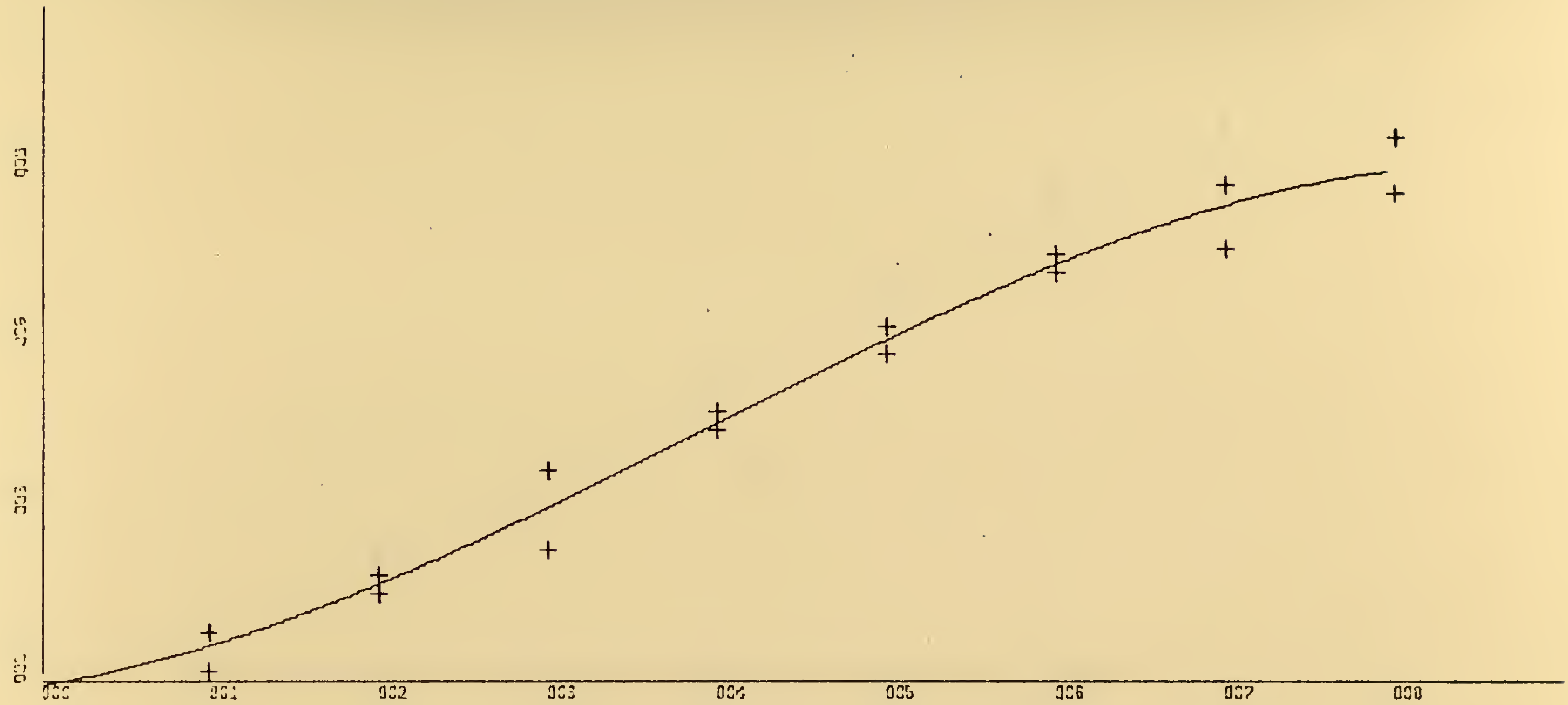
INTERPOLATED VALUES OF ML. LIQUID A VS. CHANGE IN VEL. FPS

ML	DELTA V	ML	DELTA V	ML	DELTA V	ML	DELTA V
0.0	-0.52	0.00	-0.34	0.01	-0.15	0.01	0.04
0.02	0.24	0.02	0.46	0.02	0.67	0.03	0.90
0.03	1.14	0.04	1.38	0.04	1.63	0.04	1.89
0.05	2.16	0.05	2.44	0.06	2.72	0.06	3.01
0.06	3.31	0.07	3.61	0.07	3.93	0.08	4.25
0.08	4.57	0.08	4.91	0.09	5.25	0.09	5.59
0.10	5.95	0.10	6.31	0.10	6.67	0.11	7.05
0.11	7.43	0.12	7.81	0.12	8.21	0.12	8.61
0.13	9.01	0.13	9.42	0.14	9.84	0.14	10.26
0.14	10.69	0.15	11.12	0.15	11.56	0.16	12.00
0.16	12.45	0.16	12.91	0.17	13.36	0.17	13.83
0.18	14.30	0.18	14.77	0.18	15.25	0.19	15.74
0.19	16.22	0.20	16.72	0.20	17.21	0.20	17.72
0.21	18.22	0.21	18.73	0.22	19.25	0.22	19.76
0.22	20.29	0.23	20.81	0.23	21.34	0.24	21.87
0.24	22.41	0.24	22.95	0.25	23.49	0.25	24.04
0.26	24.59	0.26	25.14	0.26	25.70	0.27	26.26
0.27	26.82	0.28	27.38	0.28	27.95	0.28	28.52
0.29	29.09	0.29	29.67	0.30	30.24	0.30	30.82
0.30	31.40	0.31	31.98	0.31	32.57	0.32	33.16
0.32	33.74	0.32	34.33	0.33	34.93	0.33	35.52
0.34	36.11	0.34	36.71	0.34	37.31	0.35	37.90
0.35	38.50	0.36	39.10	0.36	39.70	0.36	40.31
0.37	40.91	0.37	41.51	0.38	42.12	0.38	42.72
0.38	43.32	0.39	43.93	0.39	44.53	0.40	45.14
0.40	45.74	0.40	46.35	0.41	46.95	0.41	47.56
0.42	48.16	0.42	48.76	0.42	49.36	0.43	49.97
0.43	50.57	0.44	51.17	0.44	51.77	0.44	52.37
0.45	52.96	0.45	53.56	0.46	54.16	0.46	54.75
0.46	55.34	0.47	55.93	0.47	56.52	0.48	57.11
0.48	57.70	0.48	58.28	0.49	58.86	0.49	59.44
0.50	60.02	0.50	60.59	0.50	61.17	0.51	61.74
0.51	62.31	0.52	62.87	0.52	63.43	0.52	63.99
0.53	64.55	0.53	65.11	0.54	65.66	0.54	66.20
0.54	66.75	0.55	67.29	0.55	67.83	0.56	68.36
0.56	68.90	0.56	69.42	0.57	69.95	0.57	70.47
0.58	70.98	0.58	71.50	0.58	72.00	0.59	72.51
0.59	73.01	0.60	73.50	0.60	73.99	0.60	74.48
0.61	74.96	0.61	75.44	0.62	75.91	0.62	76.38
0.62	76.84	0.63	77.29	0.63	77.75	0.64	78.19
0.64	78.63	0.64	79.07	0.65	79.50	0.65	79.93
0.66	80.34	0.66	80.76	0.66	81.17	0.67	81.57
0.67	81.96	0.68	82.35	0.68	82.73	0.68	83.11
0.69	83.48	0.69	83.85	0.70	84.20	0.70	84.55
0.70	84.90	0.71	85.23	0.71	85.56	0.72	85.89
0.72	86.20	0.72	86.51	0.73	86.81	0.73	87.11
0.74	87.39	0.74	87.67	0.74	87.94	0.75	88.21
0.75	88.46	0.76	88.71	0.76	88.95	0.76	89.18
0.77	89.41	0.77	89.62	0.78	89.83	0.78	90.03
0.78	90.22	0.79	90.40	0.79	90.57	0.80	90.74

DATA SHEET LIQUID A

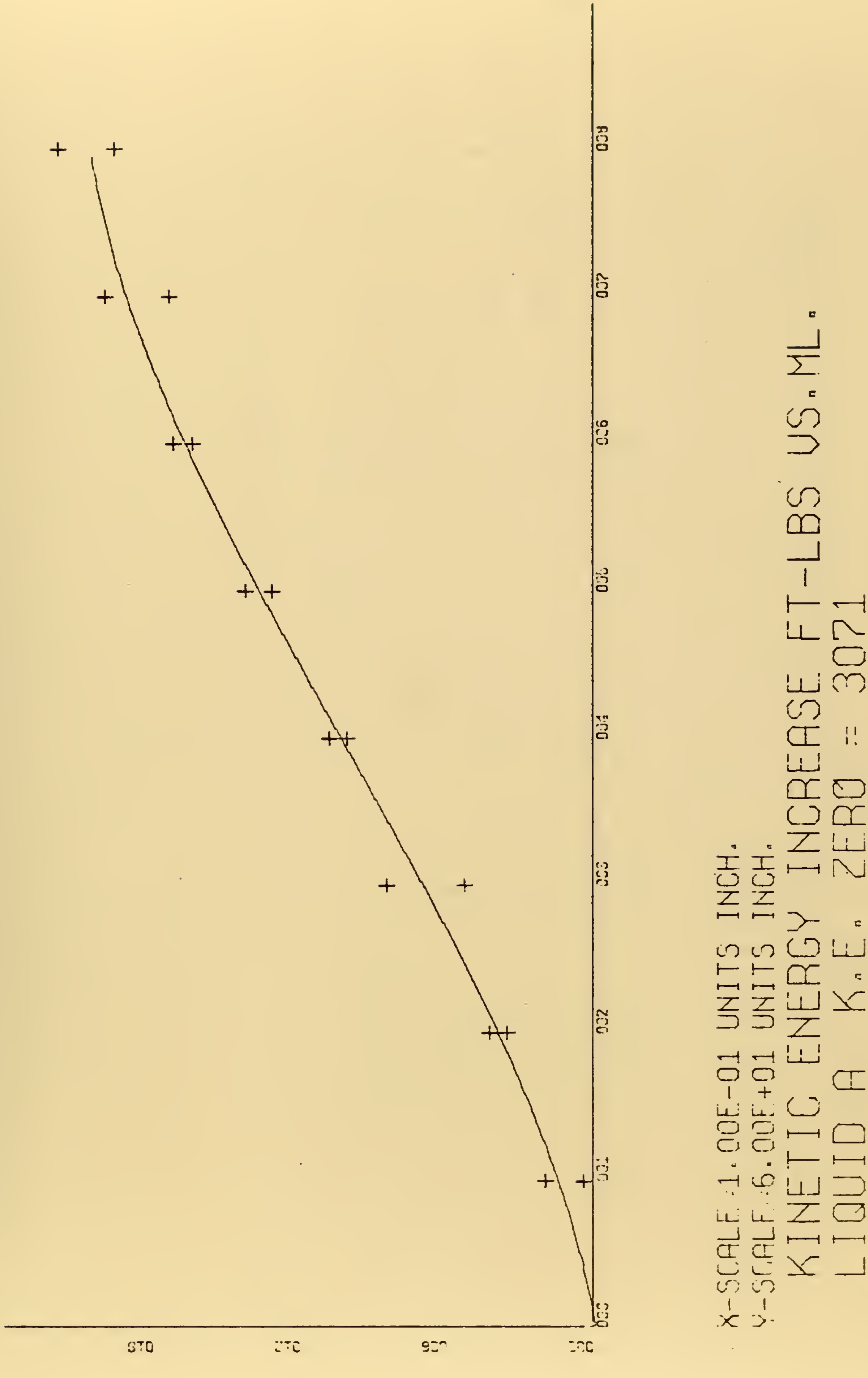
INTERPOLATED VALUES ML. LIQUID A VS. CHANGE IN K.E. FT-LBS

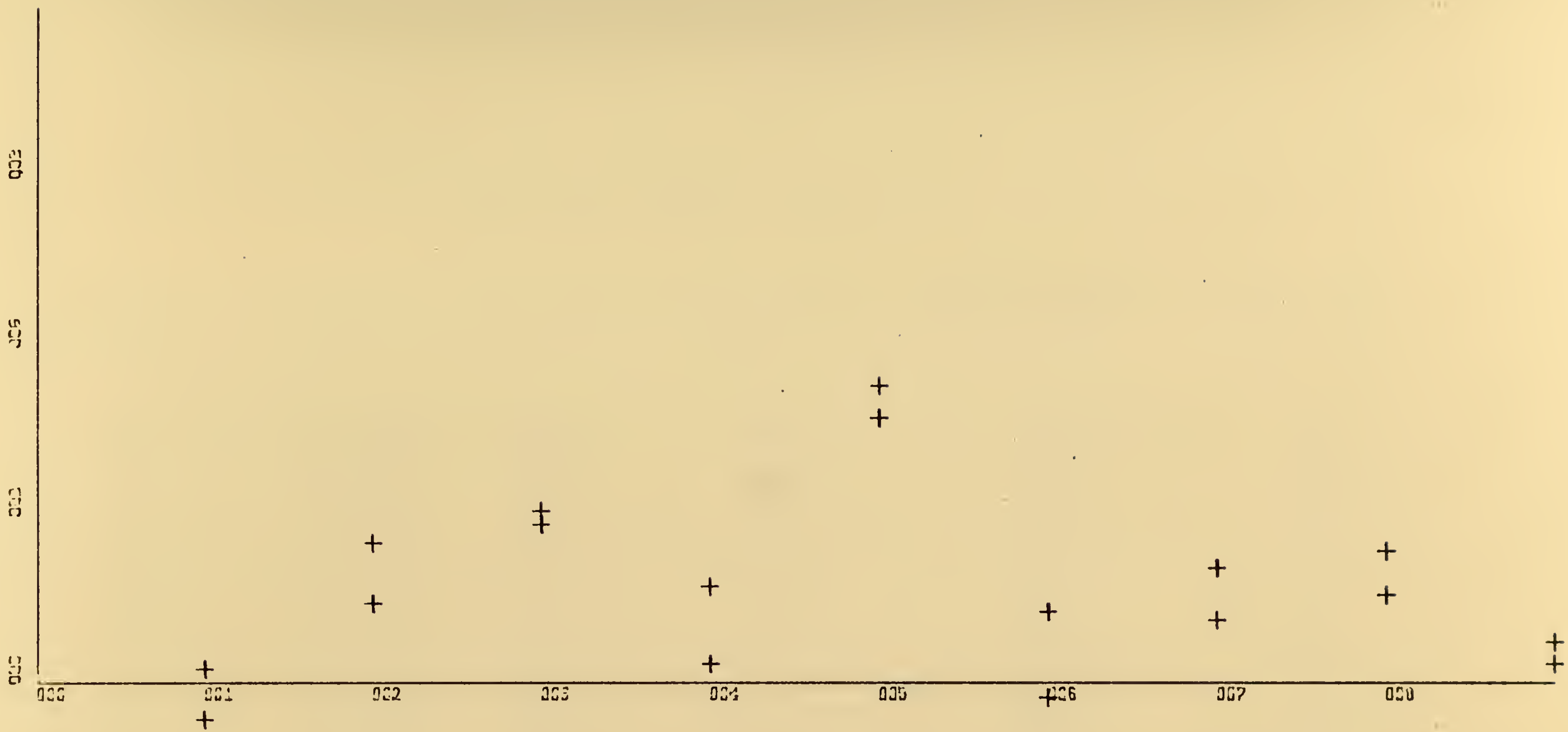
ML	DEL K E	ML	DEL K E	ML	DEL K E	ML	DEL K E
0.0	-1.18	0.00	-0.79	0.01	-0.37	0.01	0.06
0.02	0.51	0.02	0.99	0.02	1.48	0.03	1.99
0.03	2.51	0.04	3.06	0.04	3.62	0.04	4.20
0.05	4.80	0.05	5.41	0.06	6.04	0.06	6.69
0.06	7.36	0.07	8.04	0.07	8.74	0.08	9.45
0.08	10.18	0.08	10.93	0.09	11.69	0.09	12.46
0.10	13.25	0.10	14.06	0.10	14.88	0.11	15.72
0.11	16.57	0.12	17.43	0.12	18.31	0.12	19.20
0.13	20.10	0.13	21.02	0.14	21.95	0.14	22.89
0.14	23.85	0.15	24.82	0.15	25.80	0.16	26.79
0.16	27.80	0.16	28.81	0.17	29.84	0.17	30.88
0.18	31.93	0.18	32.99	0.18	34.07	0.19	35.15
0.19	36.24	0.20	37.35	0.20	38.46	0.20	39.58
0.21	40.71	0.21	41.86	0.22	43.01	0.22	44.17
0.22	45.34	0.23	46.51	0.23	47.70	0.24	48.89
0.24	50.09	0.24	51.30	0.25	52.52	0.25	53.74
0.26	54.98	0.26	56.21	0.26	57.46	0.27	58.71
0.27	59.97	0.28	61.23	0.28	62.50	0.28	63.78
0.29	65.06	0.29	66.35	0.30	67.64	0.30	68.94
0.30	70.24	0.31	71.55	0.31	72.86	0.32	74.17
0.32	75.49	0.32	76.82	0.33	78.14	0.33	79.47
0.34	80.81	0.34	82.14	0.34	83.48	0.35	84.82
0.35	86.17	0.36	87.51	0.36	88.86	0.36	90.21
0.37	91.56	0.37	92.92	0.38	94.27	0.38	95.63
0.38	96.99	0.39	98.34	0.39	99.70	0.40	101.06
0.40	102.42	0.40	103.78	0.41	105.13	0.41	106.49
0.42	107.85	0.42	109.20	0.42	110.56	0.43	111.91
0.43	113.26	0.44	114.61	0.44	115.96	0.44	117.31
0.45	118.65	0.45	119.99	0.46	121.33	0.46	122.67
0.46	124.00	0.47	125.33	0.47	126.65	0.48	127.98
0.48	129.30	0.48	130.61	0.49	131.92	0.49	133.23
0.50	134.53	0.50	135.82	0.50	137.11	0.51	138.40
0.51	139.68	0.52	140.95	0.52	142.22	0.52	143.49
0.53	144.74	0.53	145.99	0.54	147.24	0.54	148.47
0.54	149.70	0.55	150.93	0.55	152.14	0.56	153.35
0.56	154.55	0.56	155.74	0.57	156.92	0.57	158.10
0.58	159.27	0.58	160.42	0.58	161.57	0.59	162.71
0.59	163.84	0.60	164.96	0.60	166.07	0.60	167.18
0.61	168.27	0.61	169.35	0.62	170.42	0.62	171.48
0.62	172.52	0.63	173.56	0.63	174.59	0.64	175.60
0.64	176.60	0.64	177.59	0.65	178.57	0.65	179.54
0.66	180.49	0.66	181.43	0.66	182.36	0.67	183.28
0.67	184.18	0.68	185.06	0.68	185.94	0.68	186.80
0.69	187.64	0.69	188.48	0.70	189.29	0.70	190.10
0.70	190.88	0.71	191.66	0.71	192.41	0.72	193.16
0.72	193.88	0.72	194.59	0.73	195.29	0.73	195.97
0.74	196.63	0.74	197.27	0.74	197.90	0.75	198.51
0.75	199.10	0.76	199.68	0.76	200.24	0.76	200.78
0.77	201.30	0.77	201.81	0.78	202.29	0.78	202.76
0.78	203.21	0.79	203.64	0.79	204.05	0.80	204.44



X-SCALE=1.00E-01 UNITS INCH.
Y-SCALE=3.00E+01 UNITS INCH.

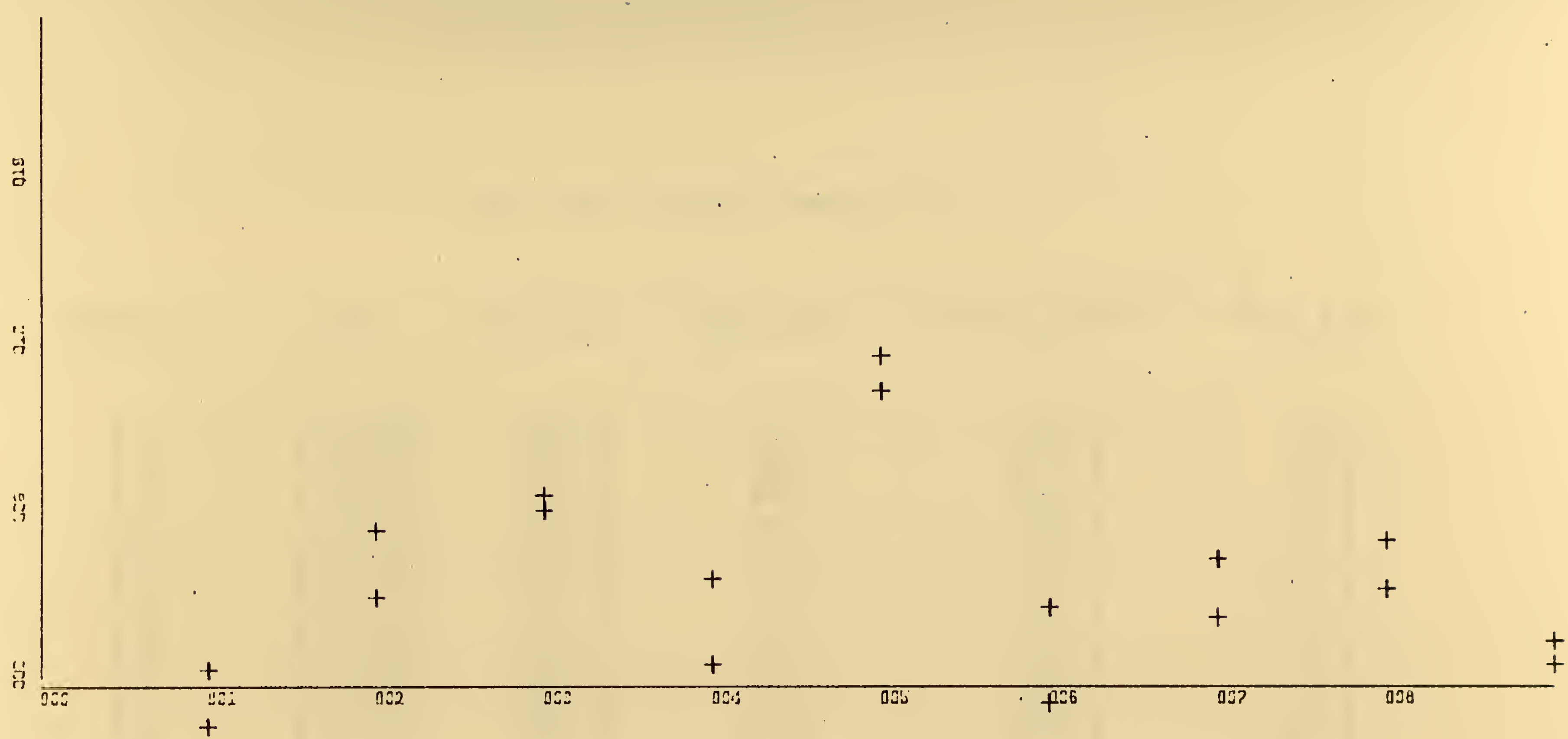
VELOCITY INCREASE FPS VS. ML.
LIQUID A VO = 2772


X-SCALE=1.00E-01 UNITS INCH.
Y-SCALE=6.00E+01 UNITS INCH.
KINETIC ENERGY INCREASE FT-LBS VS. ML.
LIQUID A K.E. ZERO = 3071



X-SCALE=1.00E+00 UNITS INCH.
Y-SCALE=3.00E+01 UNITS INCH.

VELØCITY INCREASE FPS VS.GRAINS VO = 2772
DU PØNT IMR - 4320



X-SCALE=1.00E+00 UNITS INCH.
Y-SCALE=6.00E+01 UNITS INCH.

KINETIC ENERGY INCREASE FT-LBS VS. GRAINS
DU PØNT IMR - 4320

DATA SHEET MATCHED AMMUNITION

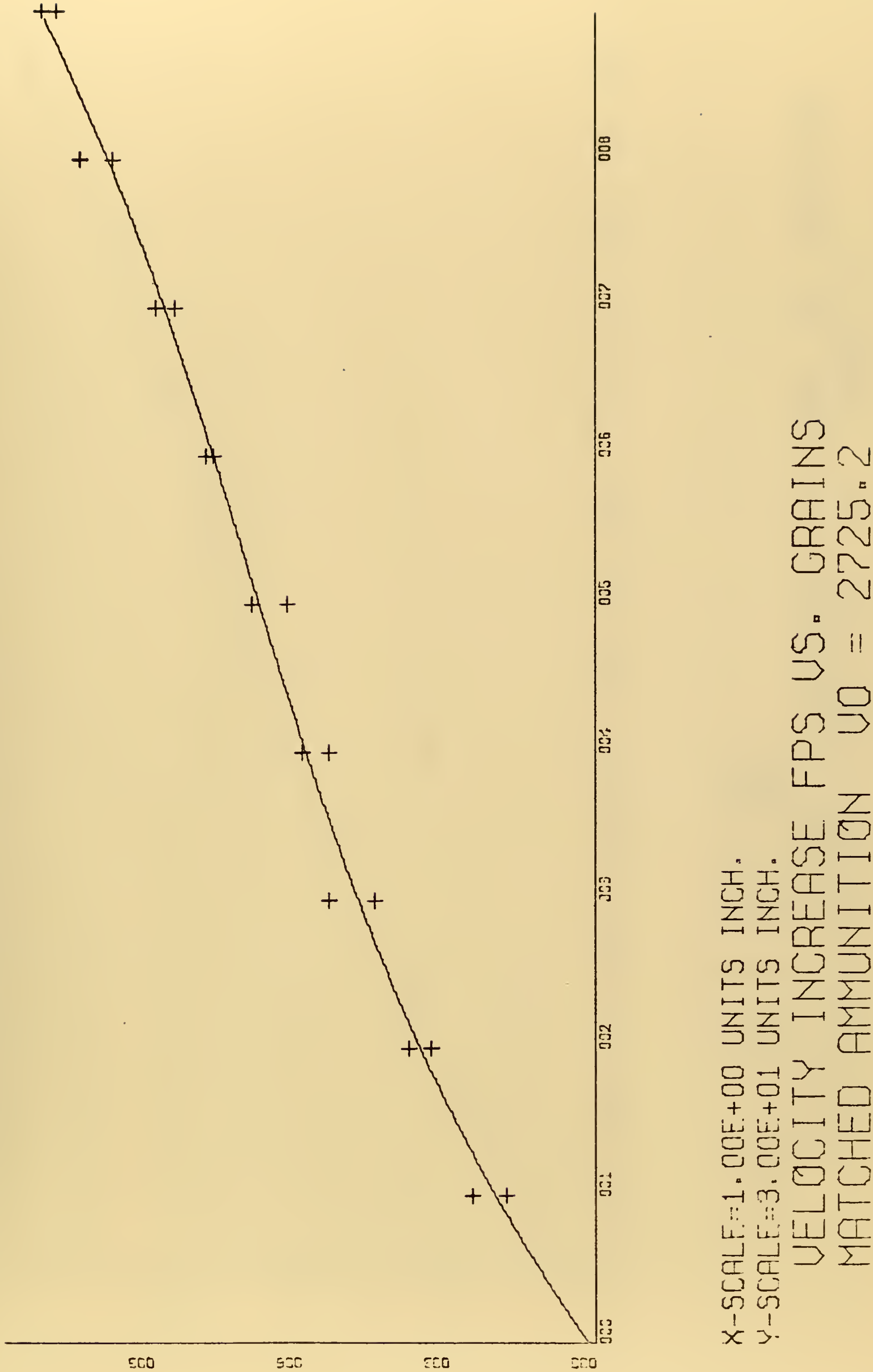
AMOUNT GRAINS	TIME SEC.	VELOCITY FT./SEC.	DELTA VEL. FT./SEC.	KINETIC ENERGY FT.-LBS.	DELTA K.E. FT.-LBS.
1.0	0.003645	2743.5	18.3	3008.5	40.3
1.0	0.003636	2750.3	25.1	3023.4	55.2
2.0	0.003619	2763.2	38.0	3046.7	83.6
2.0	0.003625	2758.6	33.4	3041.7	73.5
3.0	0.003610	2770.1	44.9	3067.1	98.9
3.0	0.003598	2779.3	54.1	3087.5	119.3
4.0	0.003598	2779.3	54.1	3087.5	119.3
4.0	0.003591	2784.7	59.5	3099.5	131.3
5.0	0.003578	2794.9	69.7	3122.2	154.0
5.0	0.003587	2787.8	62.6	3106.4	138.2
6.0	0.003568	2802.7	77.5	3139.7	171.5
6.0	0.003566	2804.3	79.1	3143.3	175.1
7.0	0.003558	2810.6	85.4	3166.4	189.2
7.0	0.003553	2814.5	89.3	3166.2	198.0
8.0	0.003542	2823.3	98.1	3186.0	217.8
8.0	0.003534	2829.7	104.5	3200.5	232.3
9.0	0.003528	2834.5	109.3	3211.3	243.1
9.0	0.003524	2837.7	112.5	3218.6	250.4

DATA SHEET MATCHED AMMUNITION
INTERPOLATED VALUES OF GRAINS POWDER VS. DELTA VEL. FPS

GRAINS	DELTA V	GRAINS	DELTA V	GRAINS	DELTA V	GRAINS	DELTA V
0.0	1.17	0.04	2.12	0.09	3.05	0.13	3.98
0.18	4.90	0.22	5.80	0.27	6.70	0.31	7.59
0.36	8.48	0.40	9.35	0.45	10.22	0.49	11.07
0.54	11.92	0.58	12.76	0.63	13.60	0.67	14.42
0.72	15.24	0.76	16.05	0.81	16.85	0.85	17.64
0.90	18.43	0.94	19.20	0.99	19.98	1.03	20.74
1.08	21.50	1.12	22.24	1.17	22.99	1.21	23.72
1.26	24.45	1.30	25.17	1.35	25.88	1.39	26.59
1.44	27.29	1.48	27.98	1.53	28.67	1.57	29.35
1.62	30.03	1.66	30.70	1.71	31.36	1.75	32.01
1.80	32.66	1.84	33.31	1.89	33.94	1.93	34.58
1.98	35.20	2.02	35.82	2.07	36.44	2.11	37.05
2.16	37.65	2.20	38.25	2.25	38.84	2.29	39.43
2.34	40.02	2.38	40.59	2.43	41.17	2.47	41.73
2.52	42.30	2.56	42.86	2.61	43.41	2.65	43.96
2.70	44.50	2.74	45.04	2.79	45.58	2.83	46.11
2.88	46.64	2.92	47.16	2.97	47.68	3.01	48.20
3.06	48.71	3.10	49.22	3.15	49.72	3.19	50.22
3.24	50.72	3.28	51.21	3.33	51.70	3.37	52.19
3.42	52.67	3.46	53.15	3.51	53.63	3.55	54.10
3.60	54.57	3.64	55.04	3.69	55.50	3.73	55.97
3.78	56.43	3.82	56.88	3.87	57.34	3.91	57.79
3.96	58.24	4.00	58.69	4.05	59.13	4.09	59.58
4.14	60.02	4.18	60.46	4.23	60.89	4.27	61.33
4.32	61.76	4.36	62.20	4.41	62.63	4.45	63.06
4.50	63.48	4.54	63.91	4.59	64.34	4.63	64.76
4.68	65.18	4.72	65.60	4.77	66.03	4.81	66.45
4.86	66.87	4.90	67.28	4.95	67.70	4.99	68.12
5.04	68.54	5.08	68.95	5.13	69.37	5.17	69.79
5.22	70.20	5.26	70.62	5.31	71.03	5.35	71.45
5.40	71.86	5.44	72.28	5.49	72.70	5.53	73.11
5.58	73.53	5.62	73.95	5.67	74.37	5.71	74.79
5.76	75.21	5.80	75.63	5.85	76.05	5.89	76.47
5.94	76.89	5.98	77.32	6.03	77.75	6.07	78.17
6.12	78.60	6.16	79.03	6.21	79.46	6.25	79.90
6.30	80.33	6.34	80.77	6.39	81.21	6.43	81.65
6.48	82.09	6.52	82.54	6.57	82.98	6.61	83.43
6.66	83.88	6.70	84.34	6.75	84.79	6.79	85.25
6.84	85.71	6.88	86.18	6.93	86.64	6.97	87.11
7.02	87.59	7.06	88.06	7.11	88.54	7.15	89.02
7.20	89.51	7.24	90.00	7.29	90.49	7.33	90.98
7.38	91.48	7.42	91.99	7.47	92.49	7.51	93.00
7.56	93.52	7.60	94.03	7.65	94.56	7.69	95.08
7.74	95.61	7.78	96.15	7.83	96.69	7.87	97.23
7.92	97.78	7.96	98.33	8.01	98.89	8.05	99.45
8.10	100.01	8.14	100.59	8.19	101.16	8.23	101.74
8.28	102.33	8.32	102.92	8.37	103.52	8.41	104.12
8.46	104.73	8.50	105.34	8.55	105.96	8.59	106.58
8.64	107.21	8.68	107.85	8.73	108.49	8.77	109.14
8.82	109.79	8.86	110.45	8.91	111.12	8.95	111.79

DATA SHEET MATCHED AMMUNITION
INTERPOLATED VALUES OF GRAINS POWDER VS. DELTA K.E.FT-LBS

GRAINS	DEL.K E	GRAINS	DEL.K E	GRAINS	DEL.K E	GRAINS	DEL.K E
0.0	2.57	0.04	4.65	0.09	6.70	0.13	8.74
0.18	10.75	0.22	12.75	0.27	14.73	0.31	16.68
0.36	18.62	0.40	20.54	0.45	22.45	0.49	24.33
0.54	26.20	0.58	28.05	0.63	29.88	0.67	31.69
0.72	33.49	0.76	35.27	0.81	37.03	0.85	38.78
0.90	40.50	0.94	42.22	0.99	43.91	1.03	45.59
1.08	47.26	1.12	48.91	1.17	50.54	1.21	52.16
1.26	53.76	1.30	55.34	1.35	56.92	1.39	58.47
1.44	60.02	1.48	61.54	1.53	63.06	1.57	64.56
1.62	66.05	1.66	67.52	1.71	68.98	1.75	70.42
1.80	71.85	1.84	73.27	1.89	74.68	1.93	76.07
1.98	77.46	2.02	78.82	2.07	80.18	2.11	81.53
2.16	82.86	2.20	84.18	2.25	85.49	2.29	86.79
2.34	88.08	2.38	89.35	2.43	90.62	2.47	91.87
2.52	93.12	2.56	94.35	2.61	95.58	2.65	96.79
2.70	98.00	2.74	99.19	2.79	100.38	2.83	101.55
2.88	102.72	2.92	103.88	2.97	105.03	3.01	106.17
3.06	107.30	3.10	108.42	3.15	109.54	3.19	110.65
3.24	111.75	3.28	112.84	3.33	113.93	3.37	115.01
3.42	116.08	3.46	117.14	3.51	118.20	3.55	119.25
3.60	120.30	3.64	121.34	3.69	122.37	3.73	123.40
3.78	124.42	3.82	125.43	3.87	126.44	3.91	127.45
3.96	128.45	4.00	129.44	4.05	130.44	4.09	131.42
4.14	132.40	4.18	133.38	4.23	134.36	4.27	135.33
4.32	136.29	4.36	137.26	4.41	138.22	4.45	139.17
4.50	140.13	4.54	141.08	4.59	142.03	4.63	142.98
4.68	143.92	4.72	144.86	4.77	145.80	4.81	146.74
4.86	147.68	4.90	148.61	4.95	149.55	4.99	150.48
5.04	151.41	5.08	152.34	5.13	153.28	5.17	154.21
5.22	155.14	5.26	156.07	5.31	157.00	5.35	157.93
5.40	158.86	5.44	159.80	5.49	160.73	5.53	161.66
5.58	162.60	5.62	163.54	5.67	164.47	5.71	165.41
5.76	166.36	5.80	167.30	5.85	168.25	5.89	169.19
5.94	170.15	5.98	171.10	6.03	172.06	6.07	173.02
6.12	173.98	6.16	174.95	6.21	175.92	6.25	176.89
6.30	177.87	6.34	178.85	6.39	179.84	6.43	180.83
6.48	181.82	6.52	182.82	6.57	183.83	6.61	184.84
6.66	185.85	6.70	186.88	6.75	187.90	6.79	188.93
6.84	189.97	6.88	191.02	6.93	192.07	6.97	193.13
7.02	194.19	7.06	195.26	7.11	196.34	7.15	197.42
7.20	198.52	7.24	199.62	7.29	200.73	7.33	201.84
7.38	202.96	7.42	204.10	7.47	205.24	7.51	206.39
7.56	207.54	7.60	208.71	7.65	209.89	7.69	211.07
7.74	212.26	7.78	213.47	7.83	214.68	7.87	215.91
7.92	217.14	7.96	218.38	8.01	219.64	8.05	220.90
8.10	222.18	8.14	223.47	8.19	224.76	8.23	226.07
8.28	227.39	8.32	228.73	8.37	230.07	8.41	231.43
8.46	232.79	8.50	234.17	8.55	235.57	8.59	236.97
8.64	238.39	8.68	239.82	8.73	241.27	8.77	242.73
8.82	244.20	8.86	245.68	8.91	247.18	8.95	248.70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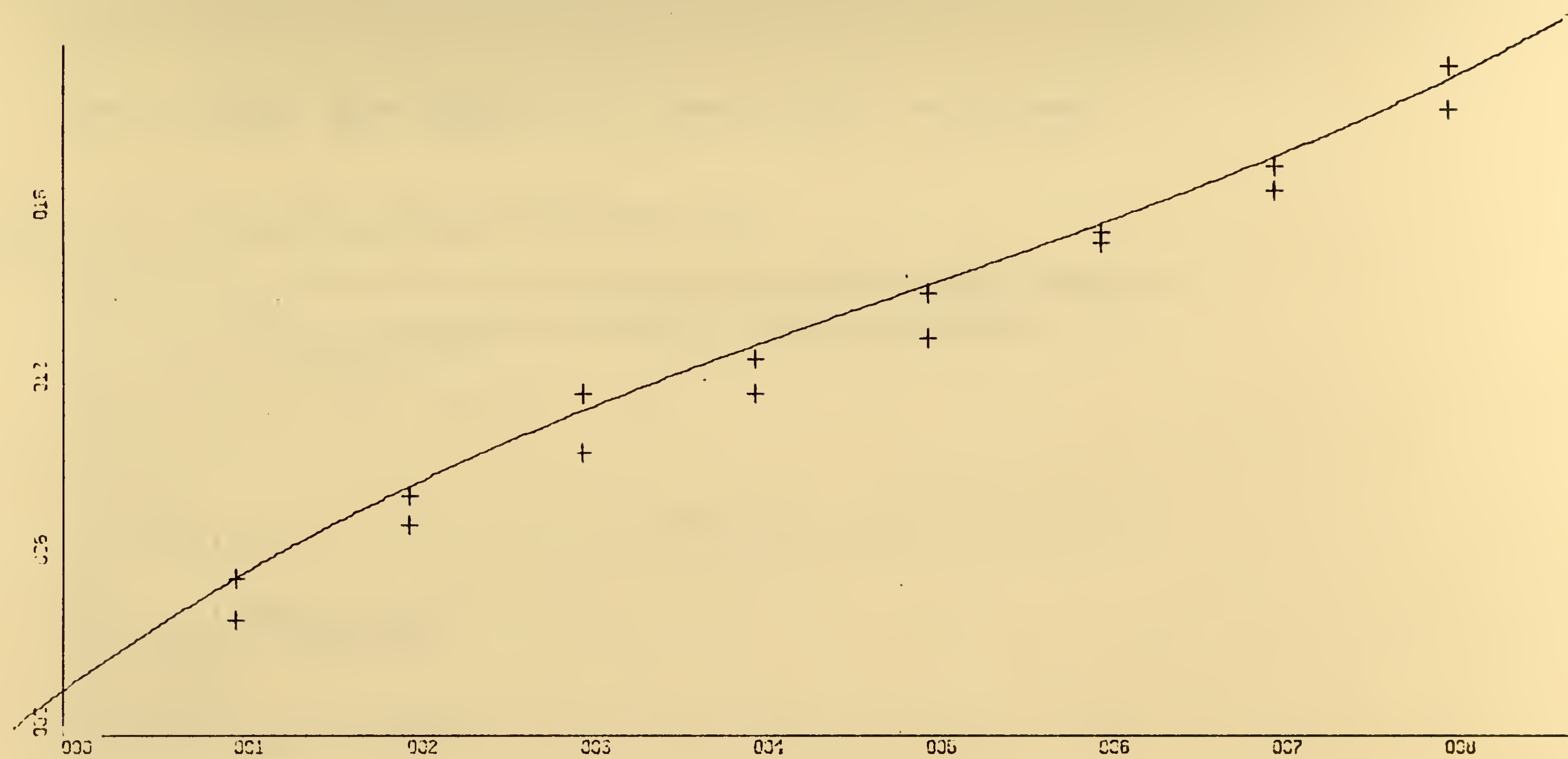
Y-SCALE=3.00E+01 UNITS INCH.
VELOCITY INCREASE FPS VS. GRAINS
MATCHED AMMUNITION V0 = 2725.2



X-SCALE=1.00E+00 UNITS INCH.
Y-SCALE=6.00E+01 UNITS INCH.

KINETIC ENERGY INCREASE FT-LBS VS GRAINS
MATCHED AMMUNITION K.E. 0 = 2968.2

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C
C
C
C     SAMPLE PROGRAM, WITH INCLUDED DATA CARDS, USED TO PLOT CURVES
C     AND DATA SHEETS FOR LIQUID A.
C
C
C
//FAILLA JOB (2641,0449,1751),'FAILLA SMC 1751'
// EXEC FORTCLGP,REGION.GO=110K
//FORT.SYSIN DD *
      DOUBLE PRECISION X(51),F2(51),WI(51),Y(51),DELY(51),B(21),SB(21),
     *X2(200),Y2(200)
      REAL*4 XX(200),YY(200),DDELY(51),FF2(51),X1(51),YY1(51),
     *T(51),V(51),DV(51),EK(51)
      REAL*8 TITLE1(10)/10*' '/
      DIMENSION TITLE(24)
      REAL*8 LABEL/'     '/,LABEL1/'     '/
      IFLAG=1
    5 LAST = 0
      IPTS=200
      NPTS=9
      M = NPTS
      MD=((2*NPTS)-2)
      KM=-3
      KN=3
      DO 1 I = 1,NPTS
      READ (5,11) X(I),F2(I)
      WRITE (6,11) X(I),F2(I)
    1 CONTINUE
      DO 4 I=1,MD
      READ (5,11) X1(I),YY1(I)
    4 CONTINUE
      DO 2 I = 1,NPTS
      WI(I) = 1.0
    2 CONTINUE
      CALL LSQPL2(M,KM,X,F2,WI,Y,DELY,B,SB,TITLE1)
      DX=(X(NPTS)-X(1))/IPTS
      X2(1)=X(1)
      JJ=1
      Y2(1)=PTS(B,X2,KN,JJ)
      DO 10 JJ=2,IPTS
      JJJ=JJ-1
      X2(JJ)=X2(JJJ)+DX
      Y2(JJ)=PTS(B,X2,KN,JJ)
   10 CONTINUE
      IF (IFLAG.GT.1) GO TO 9
      WRITE (6,100)
```

```
      WRITE (6,200)
   14 WRITE(6,300) (X2(K),Y2(K),K=1,IPTS)
      WRITE (6,400)
      DO 16 J=1,IPTS
      XX(J)=X2(J)
      YY(J)=Y2(J)
   16 CONTINUE
      DO 3 J = 1,NPTS
      FF2(J)=F2(J)
    3 CONTINUE
      READ (5,13) TITLE
      IF (IFLAG.GT.1) GO TO 6
      IFLAG=IFLAG+1
      CALL DRAW(MD,X1,YY1,1,2,LABEL1,TITLE,0.1,30.,0,0,0,0,9,4,0,LAST)
      CALL DRAW(IPTS,XX,YY,3,0,LABEL,TITLE,0.1,30.,0,0,0,0,9,4,0,LAST)
      DO 8 I=1,MD
      DV(I)=YY1(I)
    8 CONTINUE
      GO TO 5
    9 WRITE(6,101)
      WRITE (6,201)
      GO TO 14
    6 CALL DRAW(MD,X1,YY1,1,2,LABEL1,TITLE,0.1,60.,0,0,0,0,9,4,0,LAST)
      CALL DRAW(IPTS,XX,YY,3,0,LABEL,TITLE,0.1,60.,0,0,0,0,9,4,0,LAST)
      DO 7 I=1,MD
      READ(5,12) T(I),V(I),DV(I),EK(I)
      EK(I)=EK(I)+3071.
      WRITE(6,12) T(I),V(I),DV(I),EK(I)
    7 CONTINUE
      WRITE(6,500)
      WRITE(6,600)
      WRITE(6,700)
      DO 18 I=1,MD
      WRITE(6,19) X1(I),T(I),V(I),DV(I),EK(I),YY1(I)
   18 CONTINUE
   11 FORMAT (2F10.4)
   12 FORMAT( F10.6,F10.1,F10.1,F10.1)
   13 FORMAT (12A4/12A4)
   19 FORMAT( 17X,F6.1,4X,F12.6,3X,F8.1,6X,F6.1,9X,F8.1,8X,F7.1)
  100 FORMAT('1',/,/,/,/,/,/,/,/,/,37X,'DATA SHEET LIQUID A',/,20X,'INTERP
     *OLATED VALUES OF ML. LIQUID A VS. CHANGE IN VEL. FPS',/,/)
  101 FORMAT('1',/,/,/,/,/,/,/,/,/,37X,'DATA SHEET LIQUID A',/,19X,'INTERP
     *OLATED VALUES ML. LIQUID A VS. CHANGE IN K.E. FT-LBS',/,/)
  200 FORMAT('0',/,/,19X,4('ML',3X,'DELTA V',3X),/,/,/,/)
  201 FORMAT('0',/,/,19X,4('ML',3X,'DEL. K E,3X),/,/,/,/)
  300 FORMAT( 15X,F8.2,F7.2,F8.2,F7.2,F8.2,F7.2,F8.2,F7.2)
  400 FORMAT('1',17X,'NEW PAGE')
  500 FORMAT('1',/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,/,46X,'DATA SHEET LIQUID
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     *A',/,/)
 600 FORMAT('0',/,18X,'AMOUNT',8X,'TIME',6X,'VELOCITY',4X,'DELTA VEL.',
     *4X,'KINETIC ENERGY',4X,'DELTA K.E.')
 700 FORMAT(' ',15X,'MILLILITER',3X,'    SEC.    ',4X,'FT./SEC.',5X,'FT./S
     *EC.',8X,'FT.-LBS.',8X,'FT.-LBS.',/,/,/)
      STOP
      END
      FUNCTION PTS(B,X,N,I)
      REAL*8 B(21),X(200),AX,AC
      AX=X(I)
      AC=B(N+1)
      DO 9 K=1,N
      J=N-K+1
      AC=B(J)+AC*AX
    9 CONTINUE
      PTS=AC
      RETURN
      END
//GO.SYSIN DD *
 0.0      0.0
 0.1      5.4
 0.2      17.4
 0.3      30.4
 0.4      46.5
 0.5      60.9
 0.6      74.55
 0.7      82.7
 0.8      91.75
 0.1      1.9
 0.1      8.9
 0.2      19.0
 0.2      15.8
 0.3      23.6
 0.3      37.8
 0.4      44.9
 0.4      48.1
 0.5      58.5
 0.5      63.3
 0.6      72.9
 0.6      76.2
 0.7      88.4
 0.7      77.0
 0.8      86.8
 0.8      96.7
 VELOCITY INCREASE FPS VS. ML.
 LIQUID A  VO = 2772
 0.0      0.0
 0.1      12.0
```

0.2	38.7
0.3	68.4
0.4	103.9
0.5	136.4
0.6	167.4
0.7	186.0
0.8	206.7
0.1	4.2
0.1	19.8
0.2	42.2
0.2	35.1
0.3	84.3
0.3	52.5
0.4	107.5
0.4	100.3
0.5	141.9
0.5	131.0
0.6	171.2
0.6	163.7
0.7	173.0
0.7	199.0
0.8	218.0
0.8	195.3

KINETIC ENERGY INCREASE FT-LBS VS.ML.

LIQUID A	K.E.	ZERO = 3071	
.003605	2773.9	1.9	4.2
.003596	2780.9	8.9	19.8
.003583	2791.0	19.0	42.2
.003587	2787.8	15.8	35.1
.003559	2809.8	37.8	84.3
.003577	2795.6	23.6	52.5
.003545	2820.1	48.1	107.5
.003550	2816.9	44.9	100.3
.003527	2835.3	63.3	141.9
.003533	2830.5	58.5	131.0
.003511	2848.2	76.2	171.2
.003515	2844.9	72.9	163.7
.003510	2849.0	77.0	173.0
.003496	2860.4	88.4	199.0
.003486	2868.7	96.7	218.0
.003498	2858.8	86.8	195.3

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A secondary chamber was adapted to a 30-06 pressure barrel as a means for increasing muzzle velocity without exceeding the barrel pressure rating. Ignition of the secondary charge was accomplished by the high pressure gases behind the bullet. Resulting muzzle velocities were determined for various amounts of three granular and one liquid propellant. Pressure-time curves were obtained for one of the faster burning powders.

Adiabatic bomb calorimeter testing and published data were used to determine the heats of combustion. The data suggested that the rate of energy release, and not the heat of combustion, was the dominant factor in this experiment. A velocity increase of three per cent and a kinetic energy increase of seven per cent were obtained for eight milliliters of secondary charge. The results also indicated that a more optimum location of the secondary charge was possible.

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c.1 Velocity, kinetic energy, and pressure deviations resulting from the adaptation of a secondary propellant chamber on a 30-06 rifle barrel.